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DAVID TAYLOR MODEL BASIN

HYDROMECHANICS

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AERODYNAMICS

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STRUCTURAL MECHANICS

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APPLIED MATHEMATICS

TWO NEW HYDROMECHANICS RESEARCH FACILITIES AT THE DAVID TAYLOR MODEL BASIN

by

W. F. Brownell

HYDROMECHANICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

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ABSTRACT

The 36-Inch Variable-Pressure Water Tunnel and the Harold E. Saunders Maneuvering and Seakeeping Facilities at the David Taylor Model Basin are described. The information presented includes the development, construction, and use of these test facilities.

INTRODUCTION

The original towing basins of the David Taylor Model Basin became fully operative about 1940. These basins did not include wavemaking capacity in the original design since it was felt that the wavemaker in the U. S. Experimental Model Basin (EMB) would fill urgent needs for such capacity until it had been determined what kind of waves should be simulated in the new basin and what type of wavemaker would best serve future requirements. The new basin facilities also did not include increased capacity for propeller cavitation experiments on model propellers because it was felt that the 12-inch water tunnel at EMB, after transfer to TMB, would continue to meet urgent needs of the Navy until a new 24-inch water tunnel being designed for the Engineering Experiment Station (EES) was completed.

The entry of the United States into World War II, soon after operation began at TMB, raised entirely new and unforeseen problems. It soon became apparent that available or planned capacity for conducting tests in waves, for maneuvering tests, and for tests requiring high water speed and similitude of pressure relations was inadequate. The situation was improved only moderately when the 24-inch tunnel planned for EES was transferred to TMB, because this tunnel required a number of changes before it could become entirely useful. In view of this, studies were commenced about 1942 to construct a large maneuvering basin with highly sophisticated wavemaking capacity and a water tunnel larger and more flexible than the 24-inch tunnel designed for EES. The maneuvering basin received attention first; it was to be a very large rectangular basin with wavemakers at one end, spanned by a carriage traveling on rails in the direction of the long axis of the rectangle, and equipped with a second carriage or cab suspended from the main carriage traveling in the direction of the short axis of the rectangle. Construction of a rotating arm

was also planned but this was to be a separate relatively simple outdoor facility rather than a part of the maneuvering basin. Plans for these facilities were actively pursued; however, when it became apparent that they could not be completed in time to solve pressing wartime problems, work was suspended to be resumed nearly ten years later. Plans for a new water tunnel went through a similar cycle; these plans were actively pursued for a while but were not carried beyond the discussion and preliminary layout stage at that time.

When the time came, after the war, to resume these plans, the water-tunnel project received attention first. Functional specifications and the hydraulic design of a 36-in variable-pressure tunnel, shown in Figures 1, 2, and 3, were completed in April 1951[1] and a contract was concluded with the St. Anthony Falls Hydraulic Laboratory to check out this design on a 1/6-scale model.[2] Funds for its construction were provided in the Navy Public Works Program for 1952, 1954, and 1956. Construction was administered by the Bureau of Yards and Docks of the Navy; engineering plans and specifications were prepared by Seelye, Stevenson, Value, and Knecht, Consulting Engineers, aided by the Hydromechanics Laboratory and the Engineering Divisions of the Taylor Model Basin. The contract for the construction of the building, the tunnel shell, the instrumentation, installation of the pump and electric systems, and the dynamometer shafting was awarded in December 1955.[3] Work under this contract progressed rather slowly for a number of reasons but the tunnel was ready for calibration in April 1962. A further delay occurred when, during the acceptance, the up-comer tube in the resorber pit collapsed and had to be replaced. This damage is presently being repaired and it is expected that the tunnel will be ready for final calibration and use in December 1962.

Plans for the construction of the second of the major facilities, the maneuvering basin, were also resumed after the war. By this time some

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[1]References are listed on page 27.

earlier concepts had solidified and others had undergone changes in the light of wartime experiences. One important change was the decision to make the rotating arm basin an indoor facility (see Figure 4) and house it in the same building as the maneuvering basin; see Figure 5 . A second important change was the provision for installing wavemakers along two adjacent sides of the rectangular maneuvering basin instead of along one side; a third change was the replacement of the X-Y carriage by a unidirectional carriage hung on the underside of a bridge that could be moved sideways and rotated in azimuth over the basin. Finally, it was decided to try wavemakers of a rather novel design whereby waves were produced by air pressure on the water surface rather than by mechanical plunger or flapper action. To study these new features, a 1/10-scale model (see Figure 6) of the maneuvering and seakeeping basin was constructed and extensive tests were conducted.[4] These tests indicated that the functional specifications completed in March 1952[5] were sound.

The preparation of the bidding plans and specifications was administered by the Bureau of Yards and Docks through the Area Public Works Office, Potomac River Naval Command, but the actual work was done by Sverdrup and Parcel, Consulting Engineers, supplemented by the work of the Model Basin staff. Bidding plans were completed early in 1956 and funds for construction of the project were provided in the Department of the Navy Public Works Program for 1956. A contract for construction of the maneuvering and seakeeping facility was awarded in May 1956.[6] It was ready for calibration and use in 1961 and is now in full operation.

36-INCH VARIABLE-PRESSURE WATER TUNNEL

GENERAL DESIGN

In the Introduction it was mentioned that two variable-pressure water tunnels anteceded the new tunnel at TMB, namely, the 12-in and the 24-in tunnels. Both tunnels were primarily designed for propeller research. As is well known in standard model basin practice the hydrostatic pressure at, say, the propeller axis is not scaled down in proportion to the model scale, since this can be accomplished only by reducing the atmospheric pressure in the basin building, which is impractical. As long as propeller speed is not high enough to produce cavitation, this

departure from strict similitude requirements has no harmful effects; however, when propeller cavitation is to be expected, the model basin tests yield incomplete results and must be amplified by additional tests in a facility where correct pressure relations prevail. Water tunnels are the facilities in which such supplementary tests are conducted.

The new 36-in tunnel not only has a larger diameter than the older tunnels but incorporates many hydrodynamic improvements which increase the capability of this tunnel significantly. For instance, in the older tunnels noise could not be measured because the background noise of the tunnel drowned out the noise to be measured. The variability of the air dissolved in the water during a test was another limitation of the older tunnels which had a disturbing effect on the test results.

The 36-in tunnel is of a variable-speed, variable-pressure type with two interchangeable test sections--an open test section (Figure 7) and a closed test section (Figure 8). Model propellers up to 27 in. in diameter can be tested in the open section; propellers up to 18 in., in the closed section. In addition, contrarotating dual propellers up to 18 in. in diameter can be tested with the same degree of ease as single propellers. The large test section also lends itself readily to the testing of submerged bodies, such as hydrofoils, ship appendages, sonar domes, etc. Finally, provision has been made to install devices that will modify the inflow into a test propeller to simulate the variable wake behind a ship, and it is expected that the tunnel will be quiet enough to measure noise produced by test objects.

The maximum water speed in the test section is 50 knots, and the pressure at the axis of the test section can be varied from 2 psia to 60 psia. Two independent dynamometer systems are provided--one upstream and one downstream of the test section; the shafts of these dynamometers can be withdrawn so that tests can be run of single propeller using either shaft or of dual propellers using both shafts.

TUNNEL SHELL CIRCUIT

The tunnel is a closed circuit as shown in Figure 1; its overall length is 76 ft., its vertical height between centerlines of the upper

and lower horizontal limbs is 28 ft 6 in. However, the overall height of this tunnel is much greater when the resorber, which extends 78 ft into the ground below the lowest floor level is included. With the resorber, the overall height is 118 ft 6 in. The tunnel cross sections, in general, are circular.

The water in the tunnel is pumped around a closed loop emerging from a nozzle in which the stream is contracted from a diameter of 9 ft to a diameter of 3 ft; it then passes through the test section, into Diffuser I and then successively through elbow I, Diffuser II, elbow II, Diffuser III, elbow III, the resorber, elbow IV and back into the contracting nozzle. While the stream passes around this circuit the water velocity is increased and decreased, depending on whether the conduit contracts or expands. The underlying reason for this design is to obtain uniform stream velocity in the test section but low energy loss and quietness in the return circuit. At each elbow the stream is turned through 90 deg by means of guide vanes. Details are shown in Figures 9 and 10.

As mentioned, two interchangeable test sections are available, with each serving a specific purpose. The open section is used primarily for testing propellers and the closed section, for testing bodies up to 4 ft in length. Both sections are equipped with windows made from a methacrylate molding compound to permit visual and photographic observation; of course, access ports are provided also.

In the design of the tunnel, considerable thought was given to the treatment of the inside surfaces of the tunnel since trouble had been experienced in the older tunnel by paint flaking off the walls. For this reason, the tunnel sections were made of solid stainless steel or stainless clad material. The stainless steel is an 18-8 material modified by keeping the carbon content to not more than 0.04 percent. The tunnel shell is welded but sections are joined by bolted flanges and sealed tight by O-rings. Complete air and water tightness is of utmost importance in this facility; hence, great care was taken in the design of the joints and the seals around the dynamometer and pump shafts. After assembly of the sections, the tunnel was tested for tightness by loading it hydrostatically up to 150 percent of the designed pressure. Figure 11 shows the upper leg of the tunnel being assembled and readied for the shop tests.

PUMP DRIVE SYSTEM

Water is circulated in the tunnel by a 78-in adjustable four-bladed propeller pump. The rated pump discharge is 597 cu ft/sec for a head of 34 ft at 272 rpm. The rated input horsepower to the pump is 2887. Figure 1 shows the location of the pump in the tunnel circuit; Figure 12, the pump being installed at the site. To obtain maximum operating flexibility, the pump is driven by a variable-speed drive since the model propeller inputs may be up to 1000 horsepower.

The pump motor drive is of the eddy current coupling type, capable of operating in either direction of rotation. Figure 13 shows the installed drive motor and eddy current coupling. The system consists essentially of one 3500-hp, 2300-volt, 3-phase, 60-cycle motor operating at 300 rpm and a 2887-hp water-cooled eddy current coupling with one member connected to the synchronous motor shaft and the other to the pump drive shaft. The coupling and the motor each have a 15 percent service factor. The relative speeds of the driving and driven components are regulated by the excitation of the field of the coupling which has a maximum speed of 272 rpm.

An electronic speed control regulator maintains the coupling shaft output speed at any desired preset value over the speed range of zero to 272 rpm. The speed control system consists, in general, of an electronic regulator which amplifies and utilizes for correction the difference between a fixed reference voltage regulated by the speed preset and either a tachometer generator voltage or a control voltage actuated by water speed, model propeller torque, or model propeller thrust. Speed control accuracy is within ± 1/10 of 1 percent of maximum speed from 272 to 136 rpm and ± 1/20 of 1 percent of maximum speed from 136 to 27.2 rpm.

PROPELLER DYNAMOMETER DRIVE SYSTEM

The two propeller dynamometer motor drive systems, capable of rotating test propellers in either direction, are of the variable-frequency, alternating-current type. Either drive system can continuously deliver a constant torque of 2500 lb-ft over a speed range of 100 to 2100

rpm and not less than a constant horsepower of 1000 over a speed range of 2100 to 10,000 rpm. When both systems are used simultaneously, the drive system is capable of delivering to each dynamometer shaft a constant torque of 1250 lb-ft over a speed range of 100 to 2100 rpm and a constant horsepower of 500 from 2100 to 10,000 rpm. Figure 14 shows the north propeller dynamometer drive. Speed is controlled by varying the frequency of the alternating current supplied to the dynamometer drive motor. The variable-frequency supply power is generated by a variable-frequency generator driven through a water-cooled coupling by a two-speed induction motor. The speed of the generator, and thus the frequency of the dynamometer motor supply power, is varied by automatic control of the exciting current supplied to the coupling, which varies the "slip" between the two elements of the coupling. In turn, the increase (or decrease) in the slip decreases (or increases) the speed of the synchronous generator with respect to the induction motor and thereby decreases (or increases) the frequency of the current being generated and supplied to the dynamometer motor. Figure 15 shows the variable-frequency set.

Each dynamometer motor drive unit consists of one 1750-hp induction motor--2300 volts, 3-phase, 60-cycles, 3573 rpm, 4 to 78 cycles, maximum speed 4600 rpm and one gear unit with a range of 0 to 10,000 rpm and a speed increase ratio of 10,000/4600 rpm. Since motors are fundamentally constant torque devices, the physical size of the drive motor is determined by the requirement of 2500 lb-ft of torque at 2100 rpm. A straight-through drive shaft is used for tests up to 4600; the gear unit is used above this speed.

The electronic control and excitation unit for the eddy current couplings and brakes is similar to that for the pump drive. The electronic regulation system is actuated by a control signal (error voltage) proportional to speed from either a dual range tachometer driven by the model propeller drive motor shaft or by a control voltage actuated by model propeller thrust or torque. Speed control accuracy is within ± 1/10 percent of maximum speed from 10,000 to 4600 rpm and ± 1/20 percent of maximum speed from 4600 to 1000 rpm. From 1000 to 150 rpm the accuracy varies from ± 0.25 percent to ± 0.5 percent of actual operating speed.

INSTRUMENTATION

Instrumentation is provided to measure, indicate, record, and control propeller torque, thrust, and rpm; pump rpm; test section water pressure; and water speed. It is possible to preset and control during a given test run any two of the four basic variables--water speed, dynamometer speed, and either thrust or torque. The values are indicated, recorded, and controlled from the operating console shown in Figure 16. Values are indicated digitally and printed out by an electric typewriter in tabulated form.

Dynamometers

Several alternative methods were considered for measuring thrust and torque of the model propellers. These included cradled dynamometers, differential transformer gages, and strain gages. The strain gage method using foil gages was selected because it permitted measurement of thrust and torque near the model propeller. The dynamometer forms part of the propeller drive shafting (see Figure 17) and is a hollow calibrated section (see Figure 18). Three interchangeable strain gage sections are provided for each dynamometer shaft; each covers a different range of propeller torque and thrust:

Section	Torque (ft-lb)	Thrust (lb)
1	- 100 to + 900	- 400 to + 3600
2	- 200 to +1800	- 800 to + 7200
3	- 300 to +2700	-1200 to +10,800

The three range-measuring sections are provided to obtain better accuracy. Each gage section is equipped with five strain gage bridges consisting of four gages per bridge in a wheatstone bridge arrangement. Two bridges are used for independent measurement of torque, two for independent measurement of thrust, and one for monitoring shaft bending moment. A spare bridge is thus available for thrust and torque in case of trouble. A single cable mounted inside the dynamometer shaft consisting of 10 shielded pairs of 20 stranded copper wires electrically connect the strain gage section with the external slip ring and brush assembly.

The dynamometer shafting is hollow and has an outside diameter of 2 1/2 in. The portions of shafting inside the tunnel are supported by water-lubricated cutlass rubber bearings. The bearings are supported, in turn, by the shaft housing except for the bearing adjacent to the test propeller which was changed from a tungsten carbide type to a glass-impregnated "TEFLON" bearing after trouble developed with the carbide bearings. The shaft housing is supported by struts connected to the tunnel shell. The material used for the shaft is 17 Cr - 4 Ni precipitation hardened stainless steel, that of the housing a Type 304 (18-8) modified stainless steel.

Dynamometer and Pump RPM

Measurements of steady-state model propeller rpm are also indicated digitally and printed out by the electric typewriter. Speed is determined by two systems; one uses a 60-toothed wheel and magnetic type pickup which is actuated by the wheel teeth, the other a precision tachometer which is used primarily for the speed control system. The recording system consists of an electronic pulse counter register and an electrically operated readout and typewriter with necessary auxiliary equipment and circuits. When directed by the programmer, the typewriter will print rpm and the other values every 2 sec. An electronic pulse counter working off the magnetic pickup permits counting for 1 second and displays the count for 1 second.

A system similar to that used for measuring, indicating, and recording dynamometer rpm is used for the pump speed.

Test Section Water Speed and Static Pressure

Water speed is determined either from the measurement of the pressure differential across the "contraction" or by a fixed pitot tube located in the open-jet test section. The water speed is indicated digitally and printed in units of hundredths of psi (differential pressure). The measuring device is a differential bellows assembly driving a strain gage beam. Pressures are applied by means of water-filled lines from either the contraction or pitot tube to the two sides of the bellows assembly. Any differential pressure causes the center point of the two

bellows to assume a new position and deflects a cantilever beam linked to this center. When the beam deflects, the strain gages mounted on the beam provide an output proportional to the pressure differential. A differential pressure range from 0 to 60 psi can be measured by the system.

The static pressure of the water at the test section is also digitally indicated and recorded. In general, the system is the same as that used for water speed. In this case the differential pressure is between the test section and atmospheric pressure. The unit of measurement is hundredths of psia and the operating range is from 0 to 60 psia.

Pressure Regulating System

A constant-flow, positive-displacement pump system regulates the test section water pressure. The water pressure in the completely filled tunnel (no free surfaces) is changed by forcing water into or out of the tunnel. The pressure change expands or contracts the tunnel shell, thus increasing or decreasing the total water volume of the tunnel.

The system shown in Figure 19 consists of a single-screw type, 200 gal/min, circulating pump that takes its suction from two sources; namely, the discharge manifold in the vertical leg of the tunnel, which is located above the resorber, and the pressure regulating tank. The pump discharges into two receivers; namely, the intake manifold of the other vertical leg of the tunnel and the pressure regulator tank. The quantity of water passing through each of the two suctions and each of the two discharges is controlled by a pressure controller located in the test section area. When the pressure in the test section is that desired, each valve passes about 100 gpm, so that the amount of water leaving the tunnel at the discharge manifold equals the amount of water entering the tunnel at the intake manifold. In this manner, the water content of the tunnel is constant and no change in pressure occurs from this water circulation. At the same time the quantity of water entering and leaving the pressure regulating tank is also the same.

If the pressure rises in the test section, it is decreased by removing water from the tunnel as follows: An error signal from the modulating control circuit positions the valves so that the flow of water from the manifold to the pump suction is increased, and the flow from the

pressure tank is decreased, thereby maintaining approximately constant flow to the pump suction. Simultaneously, the flow into the intake manifold is decreased and that into the pressure tank increased. In this manner, the pressure rise is corrected by the decrease in the water content of the tunnel. If the pressure in the test section drops below the preset pressure the drop is corrected by adding water to the tunnel. Pressure is controlled over a range of 2 to 60 psia.

AUXILIARY SYSTEMS

A tunnel water filtering and circulating system is available. The main circulating pump is used to pass tunnel water through three filters of the replaceable multiple cartridge type at a rate of 2000 gpm or to circulate water when desired. The main circulating pump also serves to fill the tunnel from the tunnel water storage tank, after draining of the top horizontal leg of the tunnel for a change of test propellers, or to fill the entire tunnel from the water supply service. All water passes through the filter and is supplied from the Station Water Treatment Plant.

A vacuum-type deaerator with a capacity of 2000 gal/min is used. The system consists of a vertical 8-ft-diameter tank about 20 feet high into which water flows from the discharge manifold of the tunnel. The water then flows down over a series of trays to the bottom of the tank with the air being removed from the water by a vacuum pump which maintains 28 in. of vacuum above the water level. The water in the tank bottom is returned to the tunnel through the intake manifold by the main circulating pump. The water air content can be reduced from saturation at 60 deg F. to 2 cc/liter in 8 hr.

A purge system consisting of two water-powered vacuum jets served by a 150-gpm pump removes from the tunnel any air which may separate from the water and collect at high points of the tunnel, including the resorber. The water and purged air are reinjected into the tunnel, thus maintaining a constant water and air content in the tunnel.

Two refrigeration systems having a total capacity of 95 tons furnish chilled water to the air conditioning unit or to the tunnel water cooling system through two separate direct expansion water coolers. The system is capable of obtaining a 0.327-deg drop per hour in the tunnel

temperature. For normal test operations, the temperature rise is about 0.6 deg/hr but for operations when the heat input of the pump and dynamometer drives are a maximum, the rise is about 3.7 deg/hr. For these cases, the temperature is brought down when tests are not in progress by using the cooling system either overnight or weekends.

BUILDING

The 36-inch tunnel building (Figure 20) consists of three elements. The primary element houses the water tunnel, resorber, and water storage tank. This part is approximately 68 feet high, 164 feet long, and 28 feet wide. The second element houses the switchgear and motor generator sets. This section is one story high with the floor at basement level. The third element is one and three stories high and, in general, houses the offices and stairways. The building is constructed basically of structural steel with insulated precast concrete panels. The roof construction is precast and cast-in-place concrete and the roofing built up over insulation. The main building support framing and heavy equipment foundations are supported on hard rock which exists at various depths up to about 10 feet below the surface at the site.

A 25-ton electrically operated bridge crane is provided in the tunnel section. This is used for overhauls and maintenance as required and was used for erection of the tunnel. In addition, two 5-ton hand travel electric hoists and a monorail track system are provided in the lower tunnel space.

The 13.8-kv service from the main Model Basin substation has been extended to a new outdoor substation at the water tunnel site. The outdoor substation includes a 7500-kva, 3-phase, oil-immersed, self-cooled-type transformer that converts the incoming 13,800 volts to 2300 volts; and also a 750-kva, 3-phase, oil-immersed-type transformer that converts the incoming 13,800 volts to 440 volts. In addition, a 150-kva dry-type indoor transformer is available to further step down the 440-volt, 3-phase power to 120/208 volts.

STATUS

The test programs conducted in the tunnel to date have concerned

hydrodynamic calibration of the test section; correlation of the impeller pump rpm, blade angle, and test section water speed; inception of impeller pump cavitation; noise surveys of the test section; and characterization of Model Basin and ITTC propellers. These tests have been carried out with the resorber by-passed and using the open-jet test section. The tests will be continued with the resorber in the tunnel circuit when the repair of the resorber is completed. A report presenting the results of the test programs will be prepared at that time. In general, it can be stated that the hydrodynamic performance of the tunnel is satisfactory and in line with pilot model tunnel predictions of performance.

Additional detailed information on the 36-inch variable-pressure water tunnel is contained in a previous report[7] which provided information for this paper.

THE HAROLD E. SAUNDERS MANEUVERING AND SEAKEEPING FACILITIES

As mentioned in the Introduction, the maneuvering and seakeeping facilities comprise two basins, one designed primarily for testing models in an environment closely resembling that of the ocean and one designed primarily for the investigation of course stability of ships. These aims guided the design to a large extent; however, the end product proved to be a facility of great flexibility in which a multitude of investigations can be carried out. The general layout of the new facilities is shown in Figures 21 and 22, the latter being a photograph of a 1/120-scale model. Detailed descriptions of the two facilities are given in the following sections.

THE ROTATING ARM BASIN

The Basin

The rotating arm facility is a circular basin of reinforced concrete, 260 ft in diameter and 21 ft deep. It serves to tow models in circular paths through still water by means of a "rotating arm." Such tests are needed, in addition to the turning tests in free route, to analyze the turning maneuver of a given model with respect to the forces that induce and maintain the turn. The large dimensions of this basin make possible the towing of submarine models up to 20 ft in length and

surface ship models up to 30 ft in length. Steady-state speeds up to 30 knots can be obtained in one-half revolution at a radius of 120 ft; speeds up to 50 knots at the same radius can be obtained in somewhat more than one full turn. Attachment of the models to the arm and adjustments during tests are facilitated by a moveable dry dock, 26 ft long, 16 ft wide, and 18 ft deep, which can be rolled on tracks from a niche in the side wall to almost the center of the basin. Figure 23 shows the drydock, the arm, and various other details of the basin.

The Rotating Arm

The rotating arm is pivoted on a pedestal in the center of the basin and is driven by wheels mounted on its outboard end which ride on a rail laid on a raised portion of the peripheral basin side wall. The arm itself is a bridge-like structure of aluminum tubing, 8 to 10 in. in diameter and 3/16 to 3/8 in. in wall thickness; it has a span of 129 ft, a width of 20 ft, and a maximum height of 20 ft; joints were bolted or welded as shown in the photograph, Figure 24, taken during construction. The total weight of the arm is 44,000 lb and its natural vibration frequency is 3.3 cps in the vertical and horizontal modes and 4 cps in the torsional mode.

The arm pivots on a tapered roller bearing assembly mounted in the concrete center island and supported at the outer end by a peripheral track. The radial rating of the bearing at 500 rpm is 206,000 lb and the thrust rating at 500 rpm is 192,000 lb. The peripheral track construction consists of individual lengths of machined cast steel rail chairs bolted to the concrete basin wall. Flat plate hardened alloy steel (R/C 30-32) ground rail sections are bolted to the top of the rail chairs. Figure 25 shows the construction of the track. Scarf joints are used for the rails and vertical butted joints for the chairs. The rails and chairs are set to within ± 0.006 in. in height above the water surface by using a water-borne leveling bridge and micrometers in the same manner that the original basin rails were set.

Submerged models are positioned in yaw, roll, and pitch from the remote control station at the center island. A schematic arrangement of the submarine towing struts and model positioning apparatus is shown in

Figure 26. The towing struts are connected at the upper end to a strut beam attached to a rotatable yaw bearing contained in the towing carriage. Individual electric drive systems are used for positioning the model at any desired attitude with the following range of model attitudes possible:

Yaw - ± 30 deg

Roll - 10 deg outboard, 40 deg inboard

Pitch - ± 15 deg

Because they are rotatable, the struts can be oriented into the flow as desired. In addition, the strut spacing can be varied from 3 ft 6 in. to 10 ft to accommodate testing models of different lengths.

Arm Drive

The tractive force for the rotating arm is provided by two 30-in.-diameter, ground steel-tired traction wheels which are preloaded against the peripheral track surface by means of steel-tired keeper wheels mounted on pivoted shafts and loaded by nested compression springs. The wheels are preloaded to a normal force of about 61,000 lb per wheel. The drive wheels are directly coupled through a 12-ft shaft to electric motors. Figures 27 and 28 show the drive assembly at the outer end of the arm.

The electrical drive is an adjustable voltage d-c system with automatic feedback control. The two mill type d-c drive motors are each rated at 400 hp, 455 volts, 700 rpm and are capable of 250 percent overload during the acceleration of the arm. Power is supplied to the drive motors by a motor generator set consisting of a 700-kw, 900-volt, d-c generator and a 1000-hp, 2300-volt, 3-phase, 60-cycle synchronous motor. A high-gain closed-loop electronic speed regulating system operating from a tachometer feedback signal controls the d-c generator output voltage and thus the speed of the drive motor. Control for the arm drive is from a console located at the inner arm bay.

The drive system is capable of accelerating the arm to an angular velocity of 0.425 radian/sec (30 knots) within 90 deg and stabilizing at this speed within ± 0.1 percent within the next 90 deg of arm displacement. Speed regulation is within ± 0.000425 radian/sec for arm speeds up to

0.425 radian/sec and better than ± 0.1 percent of speed between 0.425 and 0.71 radian/sec.

A slip ring system is used for the transfer of power from the shore to the rotating arm. In this application the brushes rotate about stationary slip rings. The slip ring system is supported by a stationary steel shaft rising from the center island structure of the arm as shown in Figure 29.

Instrumentation

A six-component balance is provided to measure the forces and moments acting on submerged models. Modular force gages and a roll moment gage using transducers of the differential reluctance type measure the forces and moments. Each modular force gage is in the form of a 4-in. cube and is sensitive to forces in one direction only. Forward and aft assemblies are used. The forward assembly, which consists of three force balance units and the roll moment gage, is connected to the forward towing strut and to the test model. The aft assembly, consisting of three force balance units and a strut fitting, is connected to the aft towing strut and the model. The differential reluctance type transducer operates on the principle that special flexural elements when under load cause an axial core movement relative to two coils which increases one air gap and decreases another. The change in air gaps results in a differential reluctance change which alters the electrical voltage drops across the two coils and gives an output signal proportional to load. The balance is designed for the following forces and moments:

Drag	1000 lb	Roll Moment	650 lb-ft
Lift	450 lb	Pitch Moment	1750 lb-ft
Side Force	800 lb	Yaw Moment	4900 lb-ft

Recording is done by a digital system which displays and reads out the steady-state values of each force and moment. An electric typewriter prints out data. The outputs of the differential reluctance transducers are measured by an automatic null-balancing system in which the transducer and the indicator form a closed-loop servo system. The transducer output is balanced by a potentiometer. Any error signal from

the transducer is amplified and drives a servo-motor which positions the potentiometers to restore electrical balance or null to the system. The amount that the potentiometer moves is a measure of the force. Figure 30 shows the measuring, indicating, and recording instrumentation on the arm.

Submerged model roll, pitch, and yaw angles are measured and digitally indicated and recorded. The transducers in this case are analog to digital converters which connect directly to the remotely controlled attitude drive systems located at the yaw bearing.

The arm speed pickup consists of a large gear fastened to the fixed slip ring support post. The gear teeth mesh with the external gear of a pulse generator transducer located on the rotating arm structure just above the yaw bearing. The transducer includes a housing which is a stator with internal gear teeth and a magnetic pickup coil; the rotor includes the transducer external gear and a magnet. As the rotor turns, a change in reluctance occurs between the shaft gear and the housing gear, thus inducing a voltage pulse in the pickup coil. An electronic pulse counter and printer indicate and record arm speed in radians per second.

THE MANEUVERING AND SEAKEEPING BASIN

As mentioned previously, the maneuvering and seakeeping basin was designed primarily to simulate an ocean environment as closely as possible. This is quite a departure from previous model basin practice. The testing of models in waves is not a new procedure, almost every model basin in the world, including those built before 1900, has or had wave-making capacity. However, the waves produced in these basins were, in general, regular long-crested waves; this type of wave occurs in the ocean quite infrequently. Even casual observation of the ocean surface with a moderate to strong breeze blowing shows that the wave system in the ocean may have a directional pattern but is quite irregular, as though many trains of waves of different lengths and heights existed simultaneously and interfered with each other. According to modern theory, the latter is exactly what happens in nature, and in attempting to simulate the ocean wave system, the approach was taken to create irregular waves by superposition of individual waves produced by a number of wavemaking units which

can be operated in or out of phase with each other and with constant or variable frequency.

The maneuvering and seakeeping basin is 360 ft long and 240 ft wide. The depth is 20 ft except for a 50-ft trench parallel to the long side of the rectangle which is 35 ft deep. This deeper section was designed to permit free-running tests on submerged submarine models. The basin as it appeared in the construction stage is shown in Figure 31.

The wavemakers are of the pneumatic type. They are located at two adjacent sides of the rectangle as shown in Figures 32 and 33 and, as mentioned earlier, can be programmed to produce long and short crested as well as regular and irregular waves, simulating ocean waves produced by gale force winds (sea states 8-9). Regular waves from 3 to 40 ft in length and up to 2 ft in height can also be produced. To minimize wave reflection, wave absorbers consisting of grids of concrete bars are arranged at the sides of the rectangle opposite the location of the wavemakers.

A steel bridge spans the length of the basin. Attached to the underside of the bridge are tracks along which runs a controlled 15-knot towing carriage. Trolley wires suspended below the bridge provide power for ship model motors, carriage drive, instrumentation, and control. The bridge is supported on a rail system that permits the bridge to traverse one-half the width of the basin and to rotate through angles up to 45 deg from the longitudinal centerline of the basin. This rotating feature permits ship models to be towed in head or following seas at any angle from 0 to 90 deg, with a simulated speed capability far exceeding that of existing ships.

The Maneuvering Bridge and Carriage

The 376-ft free span steel bridge weighs about 230 tons and has a midspan depth of 35 ft and a constant width of 20 ft. Figure 5 shows the maneuvering bridge. Hardened steel tracks attached to the bottom of the bridge support the tow carriage. Also, a centerline hardened steel track attached to the bottom of the bridge provides a rolling surface for the carriage drive and guide wheels. The bridge and tracks were designed so that the vertical alignment of a fixed point on the towing carriage maintains its elevation within 1/8 in. as the carriage traverses the center

200 ft of run. The bridge is supported through pivots by four trucks, one under each corner of the bridge, which run on an elevated rail system at each end of the basin. The bridge drive is a Ward-Leonard type system using four 2-hp, d-c drive motors, two at each end of the bridge.

The towing carriage is a welded aluminum tubular truss structure which carries test personnel, test instrumentation, and carriage control equipment. The carriage (see Figure 34) is rectangular, 20-ft wide by 21 ft 9 in. long by 6 ft 8 inches high, and weighs about 16 1/2 tons including equipment. The carriage is supported from the bridge by four idler trolleys which run on the bridge tracks and are located at the extreme top corners of the carriage. Each support trolley includes two 10-in-diameter hardened steel wheels and one 4-in-diameter steel keeper wheel; both types of wheels are in a housing which bolts to a pad on the carriage. The carriage is guided along the bridge by four 8-in-diameter hardened steel guide wheels, two of which are spring loaded. The guide wheels ride against the vertical surface of the main traction rail of the bridge. Figure 35 shows the carriage assembly.

Carriage Drive

Two 22 1/2-in-diameter rubber-tired traction wheels preloaded against the vertical faces of the main traction rail of the bridge provide the driving force for the carriage. Each wheel is driven by an electric motor through an 8 1/4 to 1 worm gear reducer. The reducers, motors, and a tubular aluminum truss work are mounted on a steel subbase fastened to the top of the carriage. The traction wheels are preloaded to develop tractive effort without slippage by a hydraulic cylinder common to both drives which transmits its force through the preload bearings to the shafts of the traction wheels. For maximum acceleration, a preload of about 12,000 lb is required at each traction wheel. Figure 36 shows the drive assembly.

The carriage electrical drive is an adjustable voltage d-c system with automatic feedback control. Control of the carriage in either the eastward or westward direction is from a control console at one end of the carriage or from an auxiliary control station at the other end of the carriage. There are two shunt wound d-c drive motors, each rated at

125 hp, 365 volts, and 2220 rpm. Because of the accelerating requirements, each motor is capable of peak currents of 700 amp for 1 sec and 600 amp for 4 sec. A motor generator set supplies electrical power to the drive motors. The m-g set consists of a 300-kw, 750-volt, 1200-rpm generator and a 350-hp, 2300-volt, 3-phase, 60-cycle synchronous drive motor. Carriage speed is regulated by a high-gain, closed-loop electronic regulating system which operates from either a tachometer feedback signal or a loop voltage signal. The regulator controls the d-c generator output and thereby controls the drive motor speed. An open loop control system is also available in case of regulator failure.

Regenerative braking is generally used for stopping the carriage in normal testing. For high-speed runs and when maximum run lengths are desired, an arrestor cable and arresting gear system of the aircraft carrier type is used at each end of the maneuvering bridge for stopping the carriage.

A trolley system provides power, control, and instrumentation circuit connections between the maneuvering bridge and its carriage. The connections to the bridge are by means of extra flexible cable reels suspended from the building roof structure. The cable reels in turn are connected to shore by cables running along the overhead of the building. The trolleys are of the figure eight insulated type.

When towing models in waves, the steady-state carriage speed constancy is within ± 0.025 knot under 10 knots, and ± 0.25 percent of carriage speed between 10 and 15 knots. For still-water tests, the carriage speed is within ± 0.1 percent of maximum speed.

Wavemakers

Pneumatic-type wavemakers are arranged along the west and the north sides of the basin. Eight wavemaker units are located at the west end and thirteen units are along the north side; each unit about 24 ft 6 in. long. Figure 33 shows the wavemaker domes in the basin and Figure 37 is a view of the wavemaker machinery in the blower equipment room.

The wavemaker dome is only partially submerged in water and waves are generated by alternately varying the dome air pressure from positive to negative. This is accomplished by means of blowers located in

the blower equipment room which are connected to the dome by 26-in. inside diameter, 10-gage carbon steel ducting and pairs of oscillating valves. The valve system is arranged so that when air is drawn from the atmosphere it will be forced into the dome, and when air is drawn from the dome it will be forced into the atmosphere. The frequency of the oscillating valves determines the frequency, thus the lengths of the deep water waves and the wave amplitudes are varied by adjusting the blower speed. The blowers in each bank are synchronized electrically so that they always operate at the same speed. In addition, the oscillating valves in each wavemaker bank are synchronized both in phase and frequency by torsionally rigid shafting and positive power takeoff. The wavemaker controls are in a console on the elevated wavemaker control platform shown in Figure 33 along the north side of the basin.

There are two main valve drive systems, one for each bank of wavemakers. The drive systems are adjustable voltage d-c systems with automatic feedback control. Speed is regulated by a high-gain closed-loop electronic regulatory system which operates from a direct-driven tachometer feedback system. The north bank d-c valve drive motor is rated at 15 hp, 1750 rpm, and 230 volts and has current capabilities of 300 percent for 1 min. The power for this motor is supplied by a 15-kw, 250-volt, 1750 rpm, motor generator set. The west bank drive motor is rated at 10-hp, 1750 rpm, and 156 volts, and the supporting m-g set is rated at 10 kw, 1750 rpm, and 167 volts.

Two wavemaker blower drive systems are provided also. Each wavemaker blower is driven by a low slip, squirrel cage induction motor rated at 100 hp, 3-phase, 60 cycles, and 2300 volts, capable of operation over a frequency range of 8 to 80 cycles. Variable voltage, variable frequency power is supplied from two induction frequency converters, one feeding the thirteen motors of the north bank and one the eight motors of the west bank. The output frequency of the converter is controlled by a d-c system regulating the speed of the converter rotor. A 408-hp d-c motor is connected to the north converter shaft; a 252-hp motor, to the west converter shaft. A common motor-generator set supplies power to the two d-c motors and a 1000 hp, 2300-volt, 3-phase, 60-cycle, 1200 rpm synchronous motor drives the two generators.

Speed regulation is again attained by balancing the output of a feedback tachometer against a high accuracy reference voltage and feeding the difference into a regulator.

Supplementary Wavemaker Systems

Some time after the original construction contract work started it became apparent that additional control equipment was required if programmed operation of the wavemakers was to be accomplished. Therefore, the design and procurement of eight individual electro-hydraulic control systems for the west bank wavemakers was started.

Each drive unit consists of a hydraulic linear actuator and servo valve connected to the bell crank of the valve linkage of each wavemaker unit. Figure 38 shows the linear actuator. Each actuator controls the frequency and amplitude of the wavemaker valve and, thus, the frequency and amplitude of generated waves. A program transcriber-reproducer system prepares the operational program for the wavemakers on magnetic tape, and reproduces these tape signals in proper form to dictate the wavemaker operation. Regulation is furnished by a closed-loop control system which operates from a feedback signal obtained from a rotary variable differential transformer fixed to each wavemaker bell crank valve shaft. A common hydraulic pumping system rated 77.8 gpm at 1600 psi and driven by a 75-hp, 1800-rpm, 220/440-volt, 3-phase, 60-cycle motor furnishes hydraulic fluid to the servo valves.

The addition of the eight individual electro-hydraulic drives has greatly increased the operating flexibility of the wavemakers. This is due to the much faster response of the hydraulic systems and the ability to generate the same or different wave programs from each wavemaker, thus creating either long-crested irregular seas or short-crested seas. Figure 39 shows the control instrumentation for the electro-hydraulic drive system on the wavemaker control platform.

In addition to the eight individual drive units, delivery of two rotary hydraulic motor drive systems is expected in the near future. These drive systems will replace the existing 10 and 15-hp electric motor valve line shaft drives. This step was also deemed necessary to obtain the faster response and increased power required for programmed operation

of long-crested irregular waves with either bank of wavemakers. The choice of electro-hydraulic systems was based on lower cost and faster response than the electric drives considered. The drive systems will be high-gain, closed-loop servo systems. Input signals will be from precision potentiometers and magnetic tape programs and the feedback signals will be from precision tachometers. A 300-psi hydraulic power supply is provided.

Wave Absorbers

Wave absorbers are located along the south side and east end of the basin. These absorbers have been very effective in quieting the basin water after model test runs in waves. The absorbers are a discontinuous 12-deg-slope type made up of seven permeable layers resting on an impermeable beach. The permeable portion of the beach consists of rectangular precast concrete bar panels 7 ft wide by 12 ft long and 5 in. deep at the girders. The bars are 2 in. wide by 2 1/2 in. deep and are spaced at 2 in. The absorber design is the result of an intensive development and model test program in collaboration with the St. Anthony Falls Hydraulic Laboratory.[8] The wave absorber is shown in Figure 40.

BUILDING

The maneuvering and seakeeping facilities are housed in a continuous steel arch building about 695 ft long by 280 ft wide covering approximately 5 acres. Figure 41 shows the building; Figure 42, the roof framing structure under construction.

The main building structure foundations, footings, basin floor, and walls bear on hard rock which underlies the site. The 8-ft-deep steel roof truss arches, except for the two arches on the ends, are on 29-ft centers. The arches are fixed at the end and supported by reinforced concrete buttresses. The steel roof deck is covered with thermal roof insultation and built-up roofing. Each end of the building is made up of insulated metal wall panels supported by steel columns and girts. The outside sheet of the insulated panel is fluted aluminum and the inside is metal-coated steel. Footing foundations and walls are reinforced concrete for a minimum height of 3 ft above the first floor level. The sides of the building are constructed of insulated wall panels and reinforced concrete.

The heating and ventilating system of the building is similar to that used in the main towing basin of the Model Basin. An indoor temperature of 67° F, and 60 percent of relative humidity when the outdoor ambient termperature is 0° F. can be maintained. One complete change of building air can be made per hour in the summer. The heating and ventilating units are the wall type and are hung from the perimeter walls of the building. Exhaust ventilation is provided by motorized roof exhausters.

Overhead traveling cranes and/or monorail hoist systems are available in the electric equipment room, the fitting room area, over the centerline of the basin, and in the wavemaker blower room.

The primary electrical service for the maneuvering and seakeeping facilities is a 13,800-volt, 3-phase, 60-cycle, effectively grounded system. Power distribution is from the main Model Basin substation to 13.8-kv indoor switchgear. One of the 13.8-kv switchgear feeder units is connected by 15-kv cable to an outdoor substation located adjacent to the south wall of the building. The outdoor substation is rated at 5000/(6250 future) kva, 13,800/2400 volts. In addition, a double-ended 13,800-volt substation consisting of two transformers each rated at 750 kva is located indoors.

Three sources of model-motor power are available, one each, for the rotating arm, maneuvering bridge carriage, and the fitting room. The systems are designed so that any two of these supplies can be used at any of the three test sites. Motor generator sets capable of supplying 20 hp at 230 volts supply the model power. The output is variable from 20 to 400 volts d.c. with a maximum output of 75 amp. At each location are provided two high-gain, closed-loop, electronic speed-regulating systems, which operate from either a tachometer or a loop voltage feedback to control the d-c generator output voltage, and thus the model motor speed.

Potable, basin fill, recirculating, and fire water lines are provided and connected to existing station lines. The water for filling the basins comes from the Station Water Treatment Plant. A cartridge-type water filter plant filters the basin water locally by recirculation and

thus relieves the main filter plant of the station. The basins are gravity drained by means of 24-in. cast iron pipe which connects the basin floor drains with a wet well in the building. The wet well contains two vertical turbine pumps that discharge the water to a storm sewer.

Overhead catwalks and camera platforms provide for observing and photographing. In addition, each basin contains an observation room located in the basin wall for visual observation and photography of special tests in the vicinity of the wall.

STATUS

The maneuvering and seakeeping facilities are in active use. Submarine series tests, PCH craft tests, and correlation tests are typical of those conducted in the rotating arm basin to date. In the initial shakedown, the correlation tests received the greatest emphasis. The submarine model correlation tests were conducted to compare, where applicable, previous stability test results from the TMB Planer Motion Mechanisms MK 1 System and those of other rotating arm basins. The performance of the rotating arm has been satisfactory and the results of the correlation tests will be furnished in a separate report. Figure 43 shows a 15-ft ALBACORE model being tested in the rotating arm basin.

In the maneuvering and seakeeping basin, intensive calibrations of wavemakers and waves are being conducted and are not quite complete. These tests have involved measurements of both regular and irregular long-crested wave profiles at various locations in the basin. When this work is finished, a separate report will be issued. Typical of the model tests conducted to date are bulk carrier self-propulsion tests to measure the powering in waves, CVA 59 FORRESTAL tests to predict motions in any seaway, and Series 60 model slamming studies. Figure 44 shows a 16-ft high-speed replenishment ship model being tested in waves and Figure 45 shows a 22-ft radio-controlled model of a fire support ship making a turn in the basin.

Further detailed information on the maneuvering and seakeeping facilities is contained in a prior report[9] that provided information for this paper.

CONCLUSIONS

The 36-inch variable-pressure water tunnel and the maneuvering and seakeeping facilities add greatly to the testing capability of the Model Basin. Fundamental, applied, and experimental research and development programs can now be readily carried out in areas where research tools in the form of test facilities were lacking. As a result the operating capabilities of the fleet will be significantly improved by this ability to furnish the additional hydrodynamic data needed for design purposes.

ACKNOWLEDGMENT

The hydromechanic facilities described in this paper are due to the efforts of many members of the Model Basin staff, the Bureau of Ships, the Bureau of Yards and Docks, and numerous contractors. Acknowledgment is given to the Commanding Officers and Directors of the Taylor Model Basin who furnished strong support and encouragement through the conception, development, and construction phases of the facilities. In addition, acknowledgment is extended to Dr. F. H. Todd who was Technical Director of the Hydromechanics Laboratory when the development and construction of the specific facilities described were started and to Dr. K. E. Schoenherr, Chief of the Hydromechanics Division from 1942-45 and Technical Director of the Hydromechanics Laboratory from 1958 to the present, who edited this paper and contributed background information. Thanks are given also to Captain J. A. Obermeyer, Commanding Officer and Director of the Taylor Model Basin, for permission to publish this paper.

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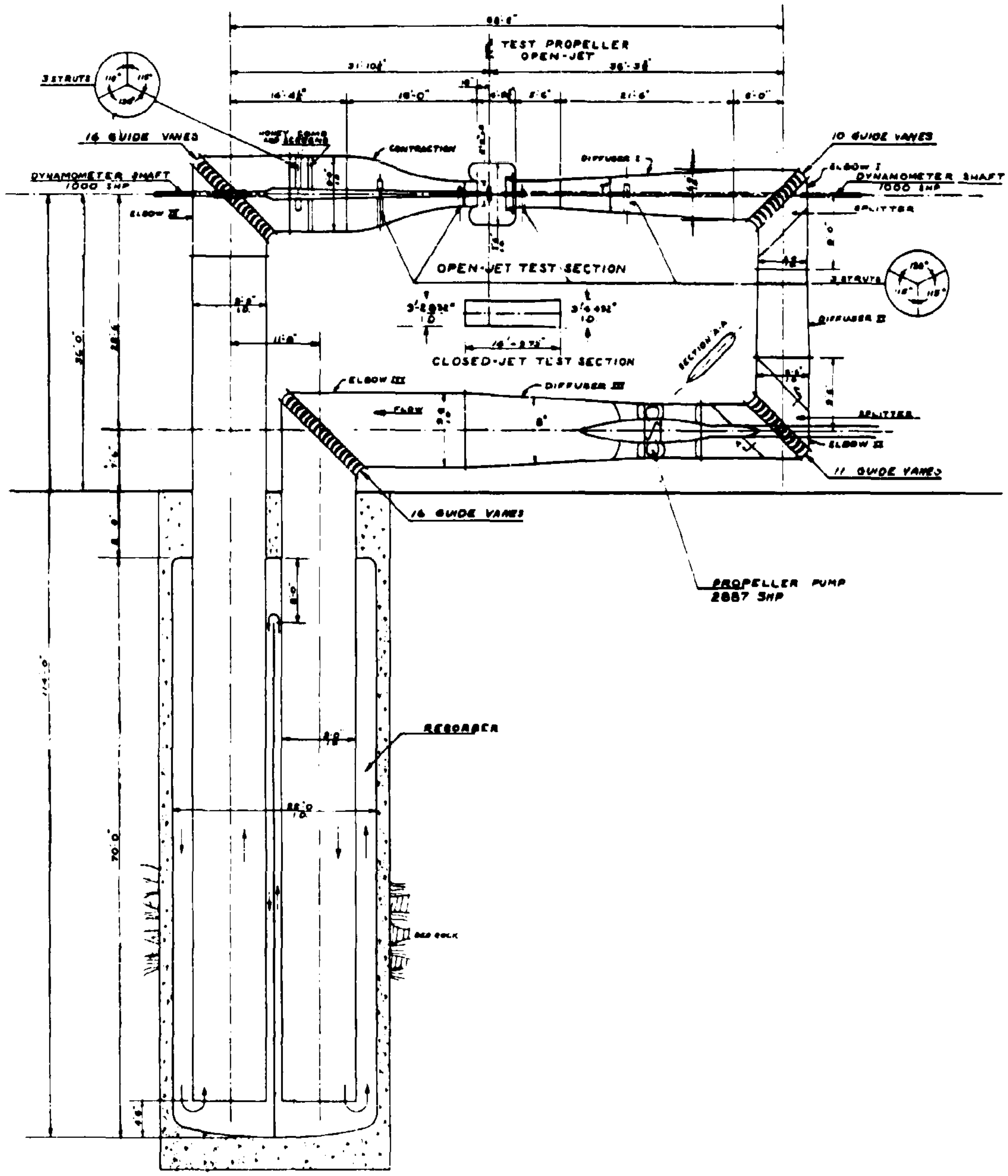


Figure 1 - 36-Inch Water Tunnel Circuit, Vertical Cutaway Elevation

Figure 2 - 36-Inch Water Tunnel with Open-Jet Test Section, Upper Leg, Looking North

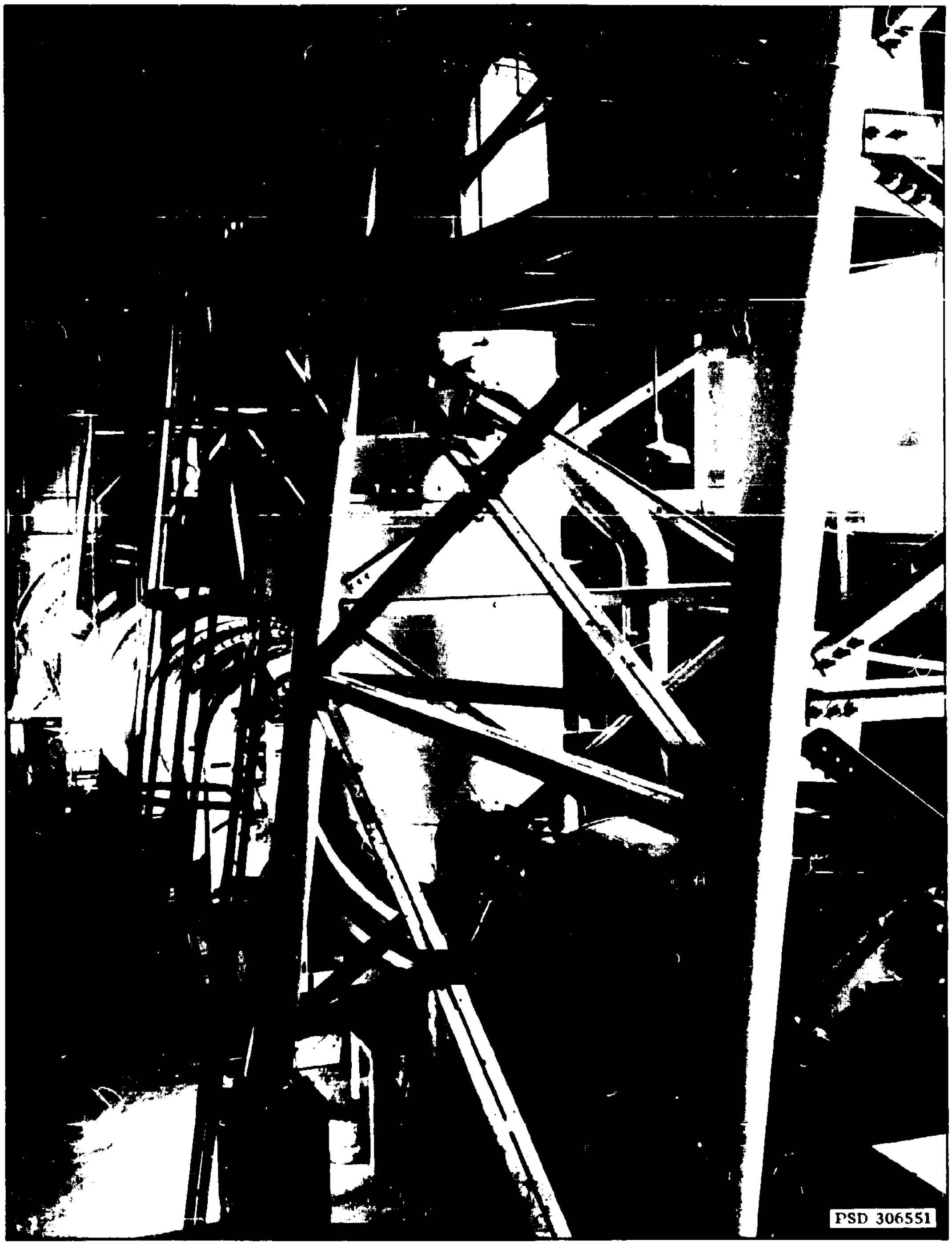


Figure 3 - 36-Inch Water Tunnel, Lower Leg, Looking North

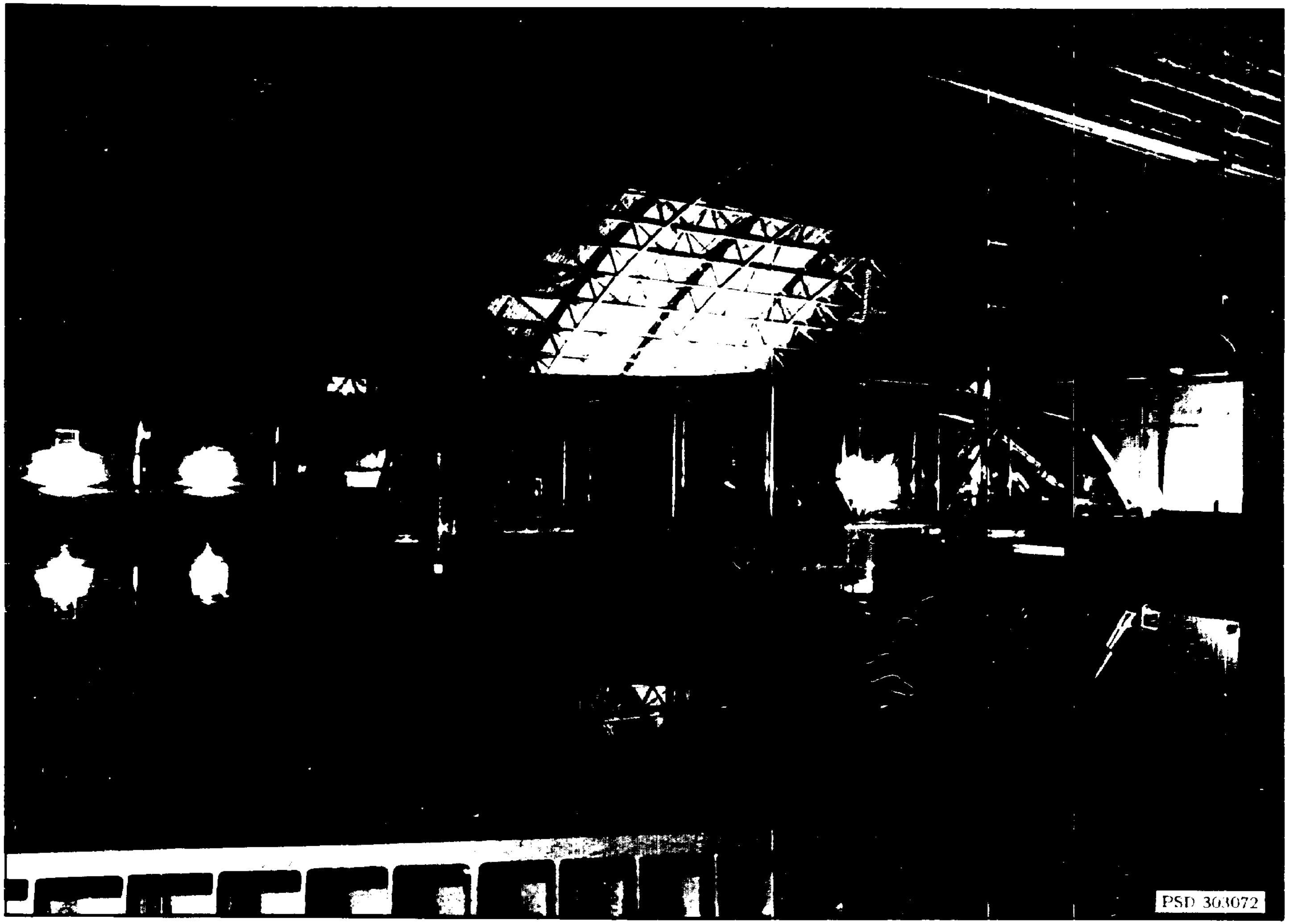


Figure 4 - Rotating Arm Basin, Looking South at Arm and Track

Figure 5 - Maneuvering and Seakeeping Basin, Looking South at Bridge and Towing Carriage

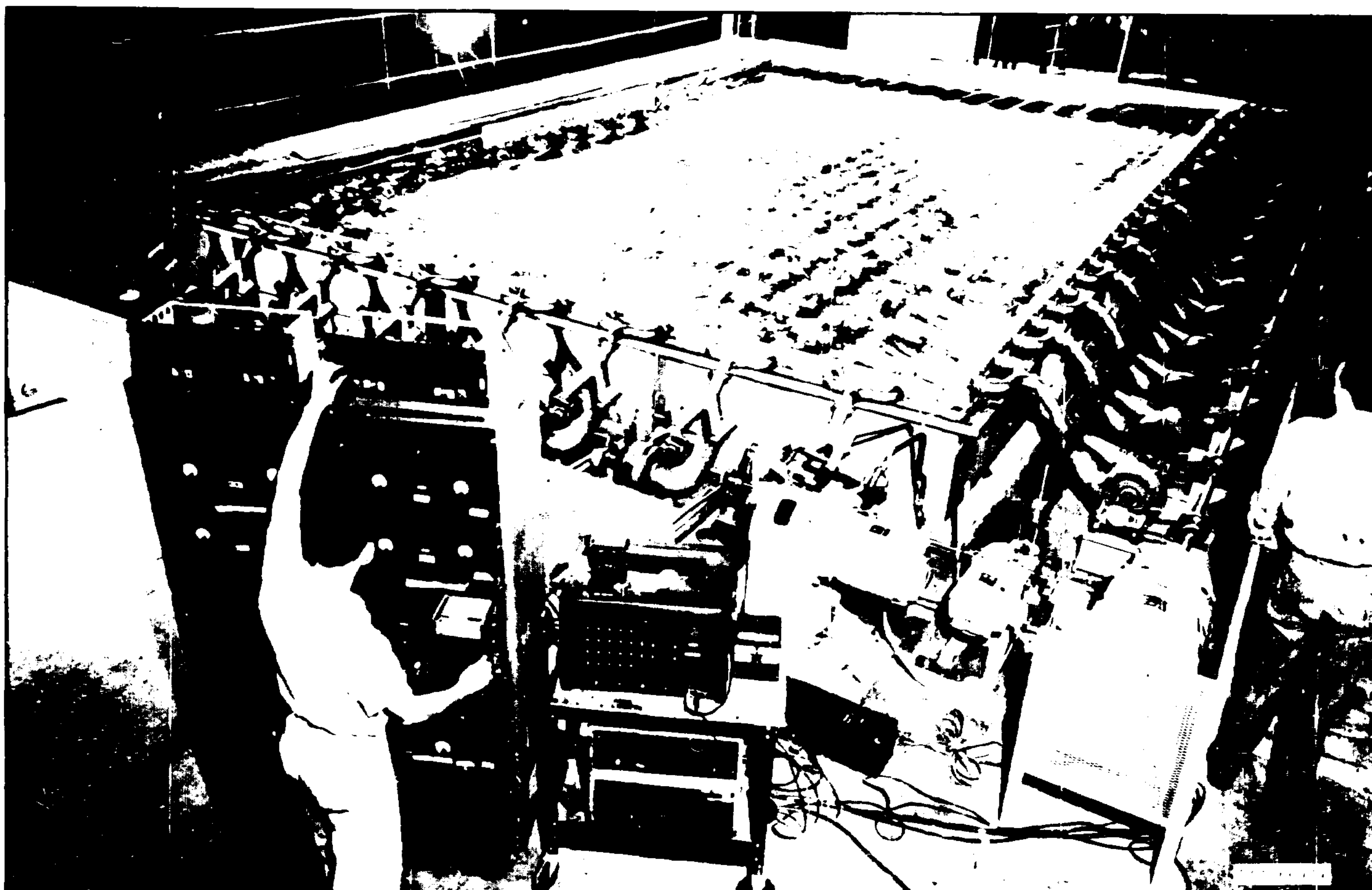


Figure 6 - Tenth-Scale Model of Maneuvering and Seakeeping Basin

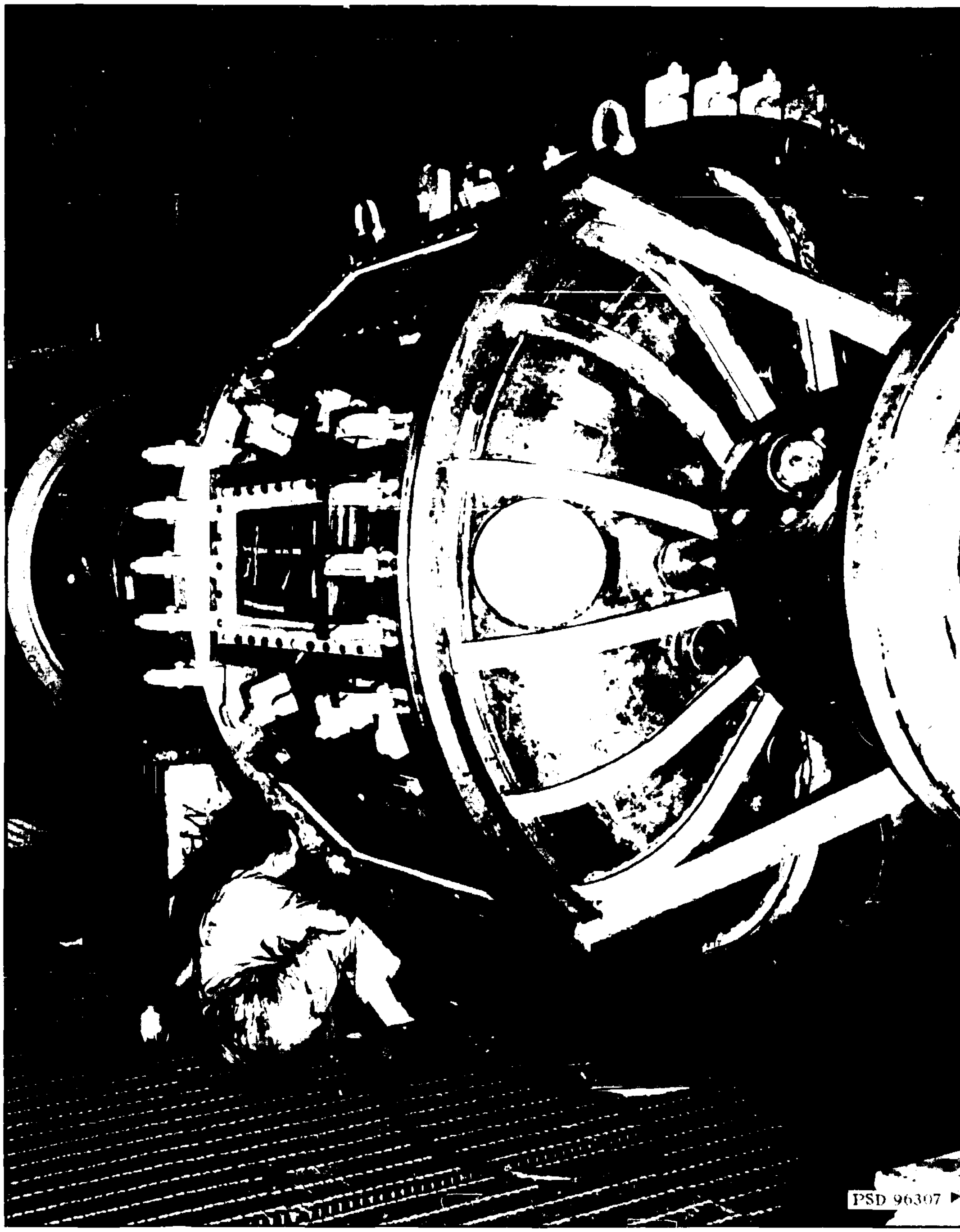


Figure 7 - 36-Inch Water Tunnel with Open-Jet Test Section Being Installed

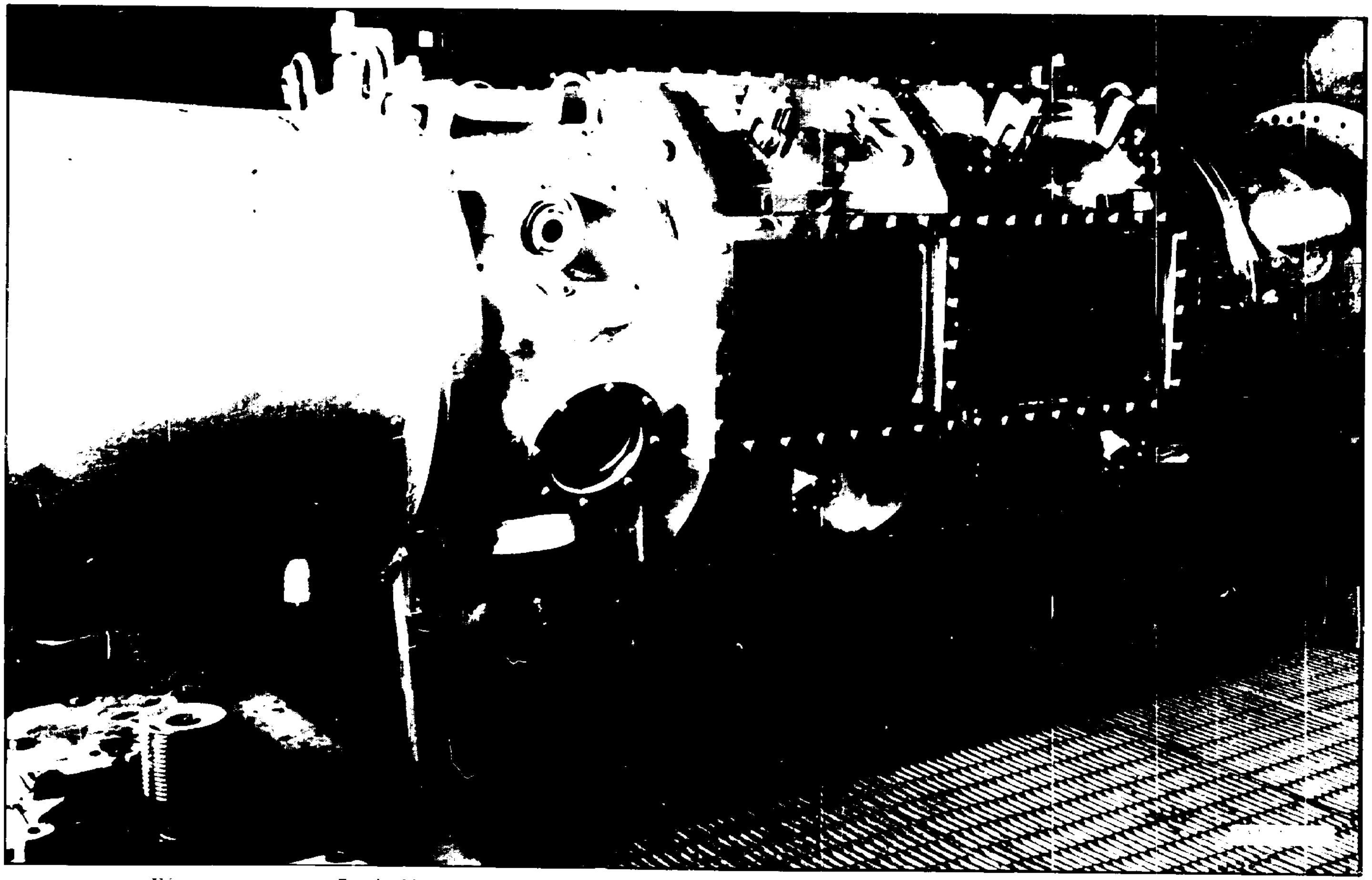


Figure 5 - 36-Inch Water Tunnel with Closed-Jet Test Section in Stored Location

Figure 9 - 36-Inch Water Tunnel Elbow Being Fabricated

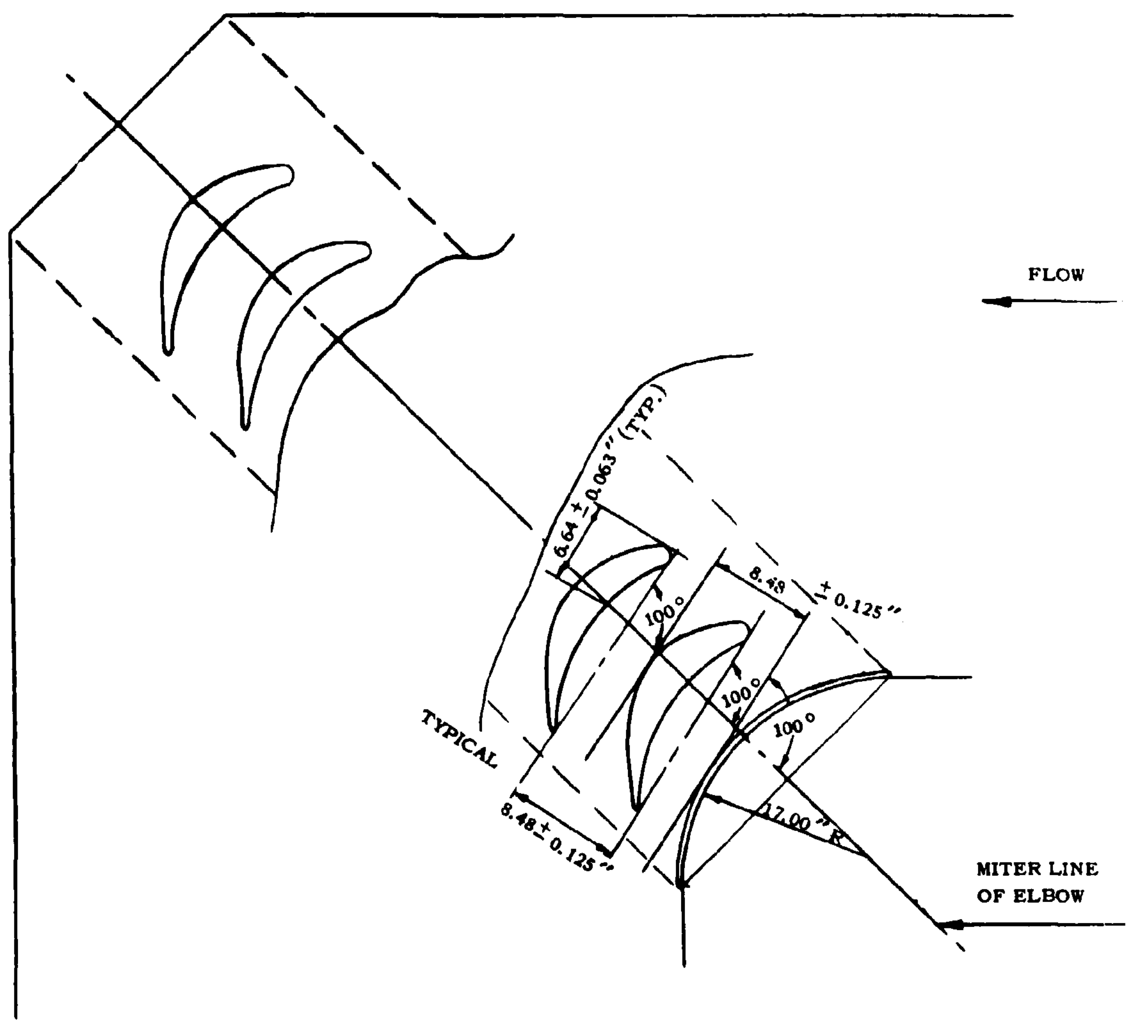


Figure 10 - 36-Inch Water Tunnel, Elbow Guide Vanes Configuration

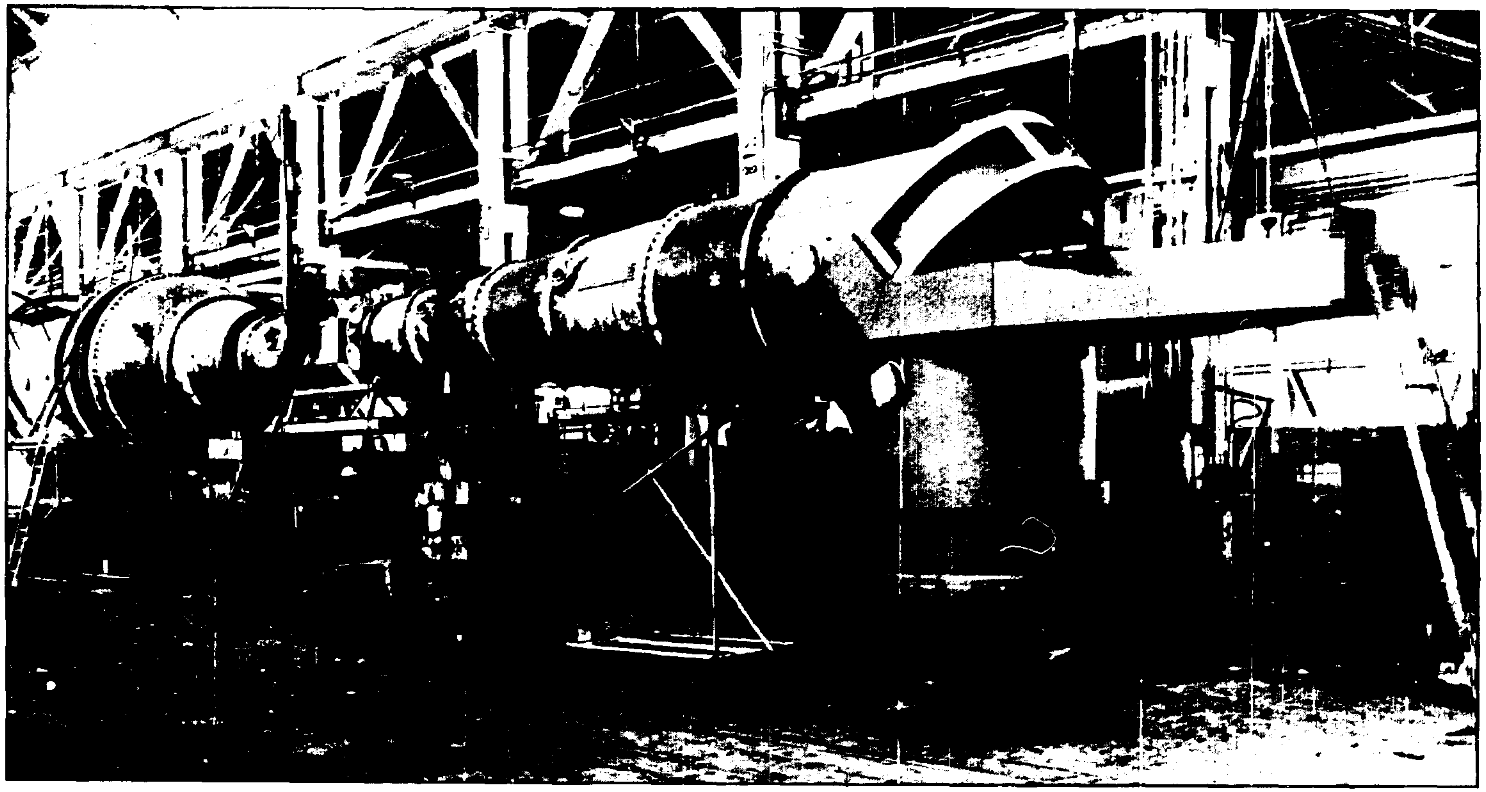


Figure 11 - 36-Inch Water Tunnel with Closed-Jet Test Section Being Assembled for Shop Test

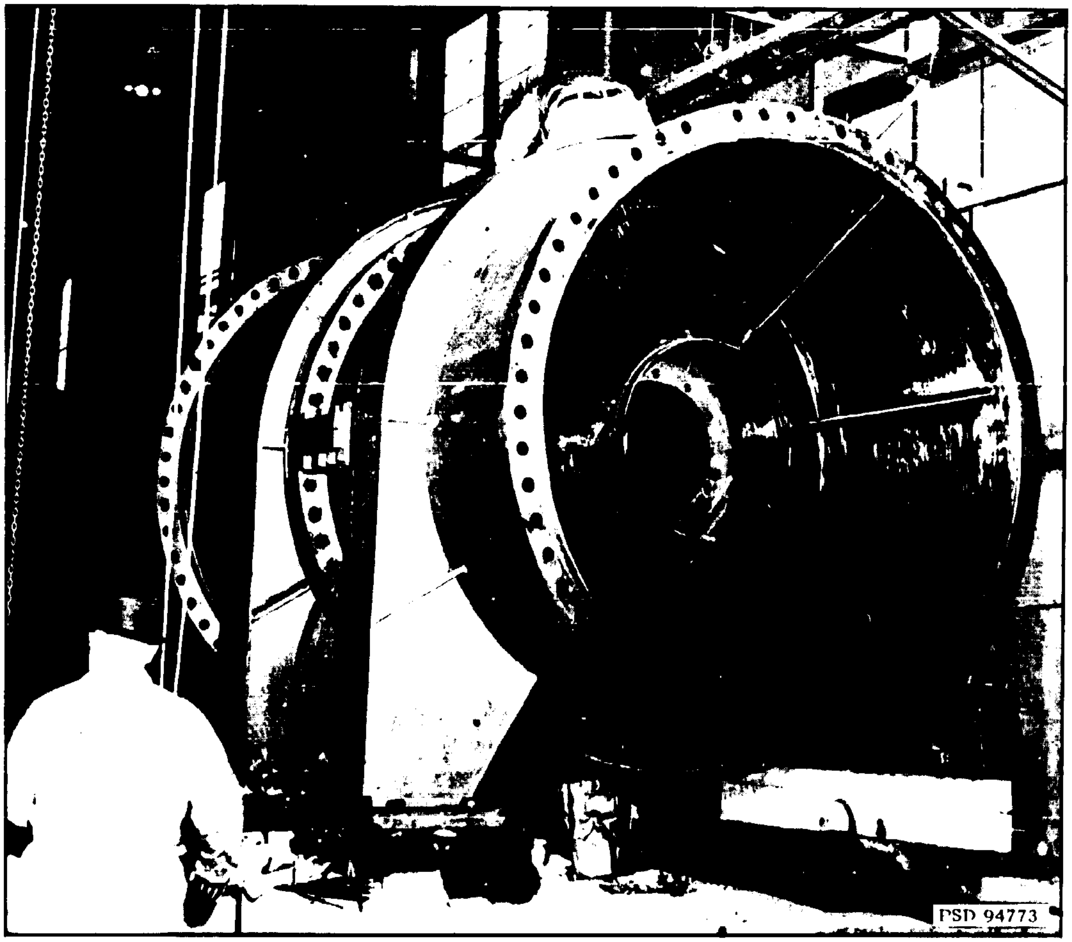


Figure 12 - 36-Inch Water Tunnel Pump Being Installed at the Site

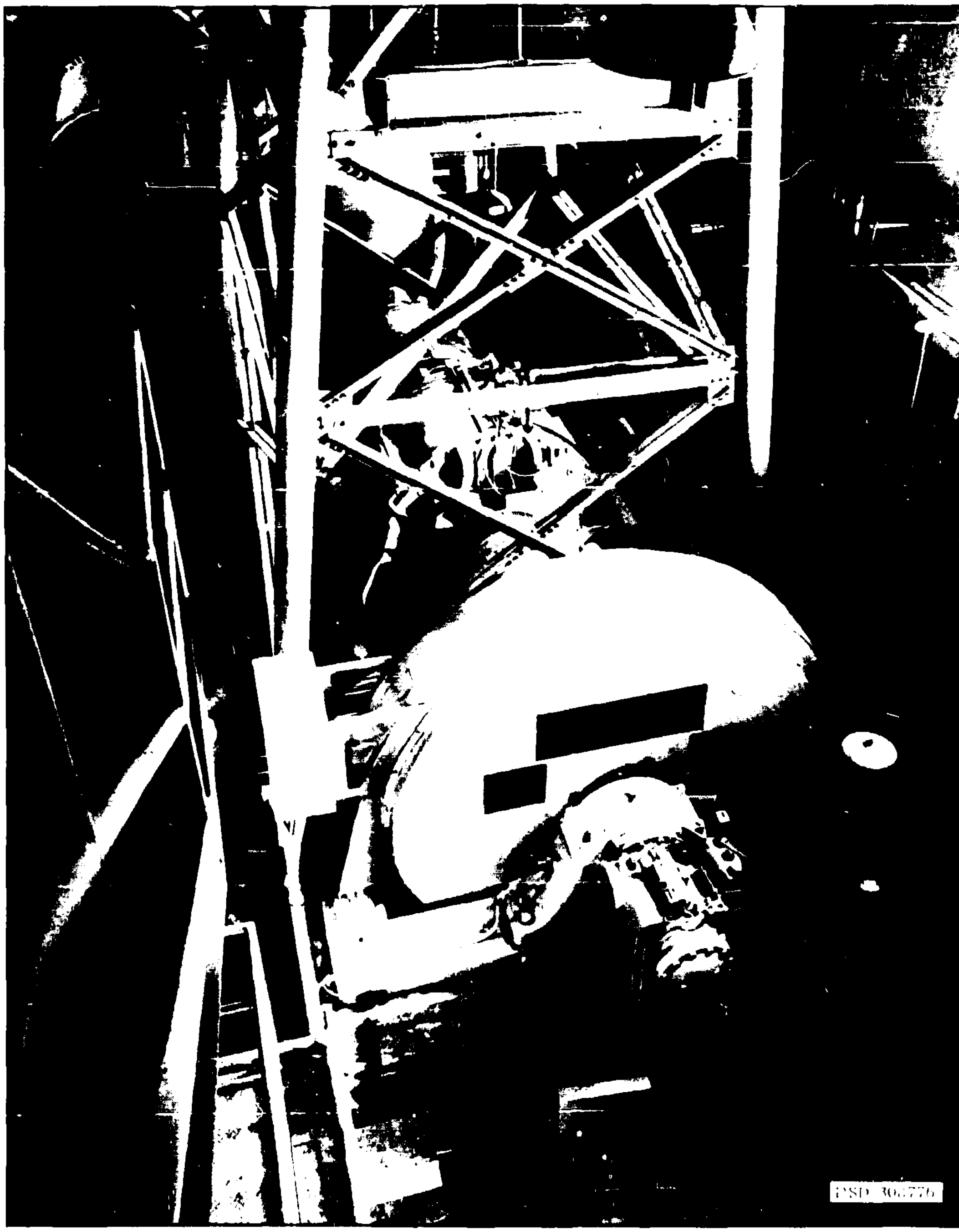


Figure 13 - 36-Inch Water Tunnel Pump Drive System

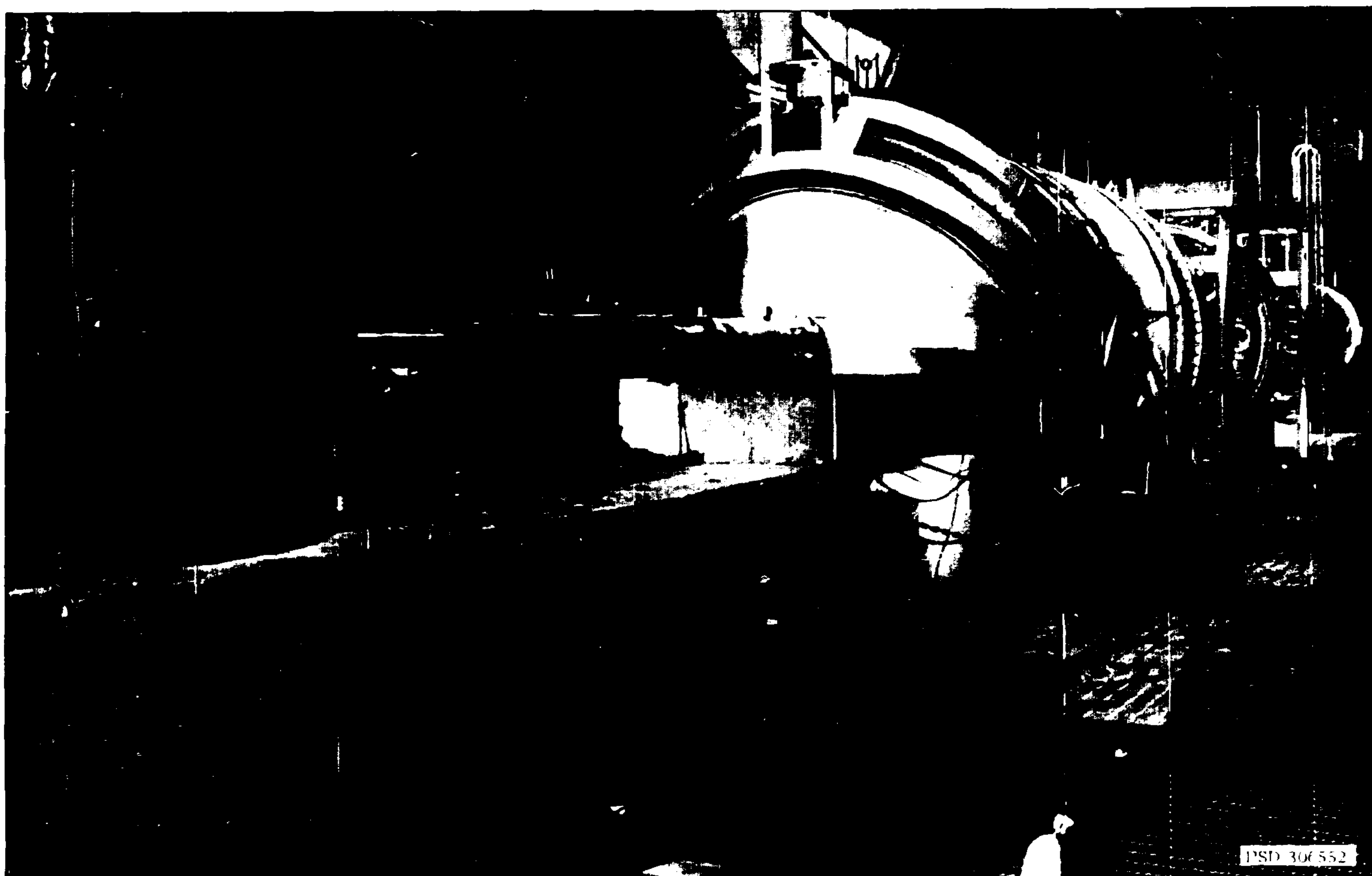


Figure 14 - 36-Inch Water Tunnel North Propeller Dynamometer Drive with Speed Increase Gear Unit on Floor

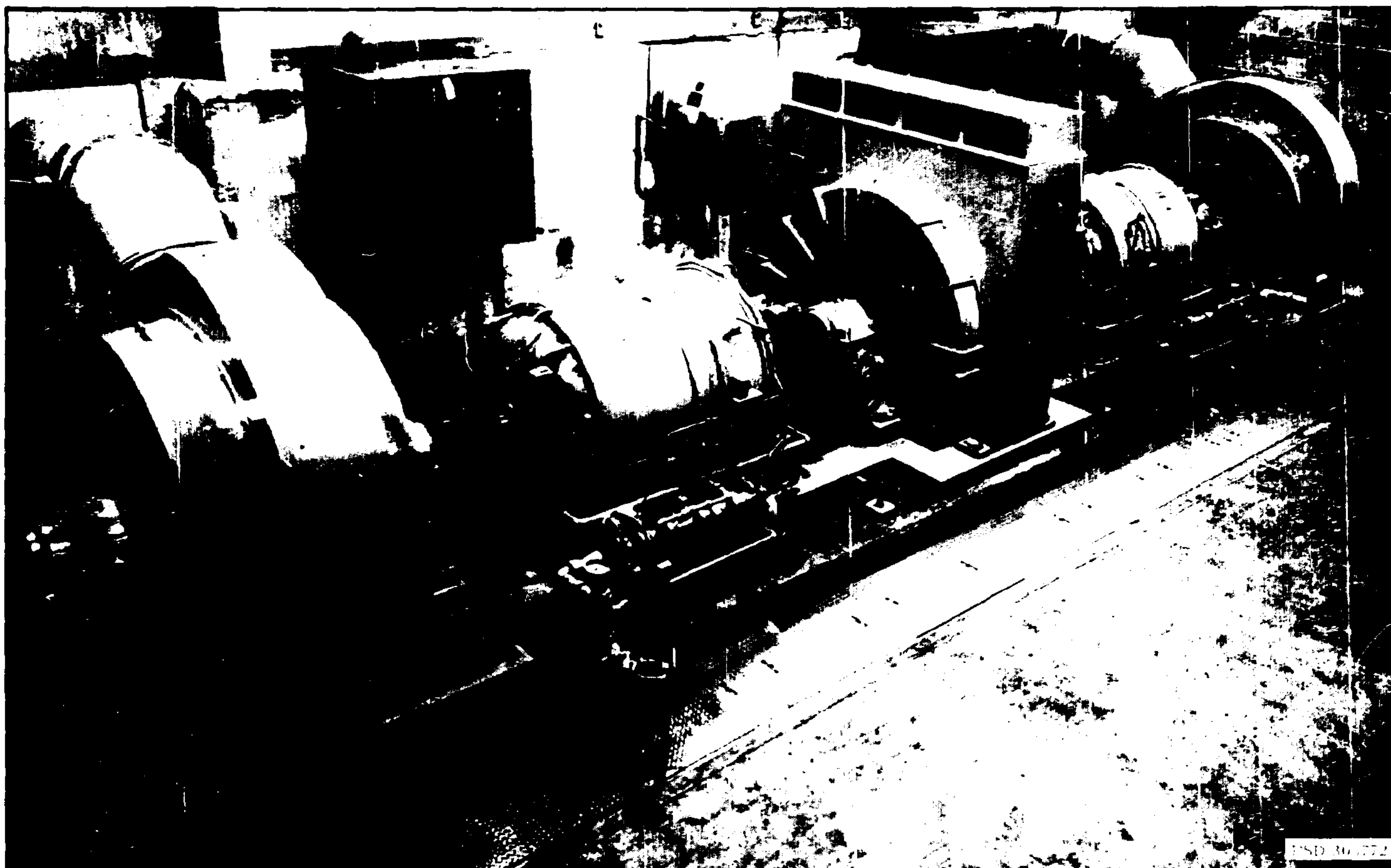


Figure 15 - 36-Inch Water Tunnel Propeller Dynamometer Variable-Frequency Set

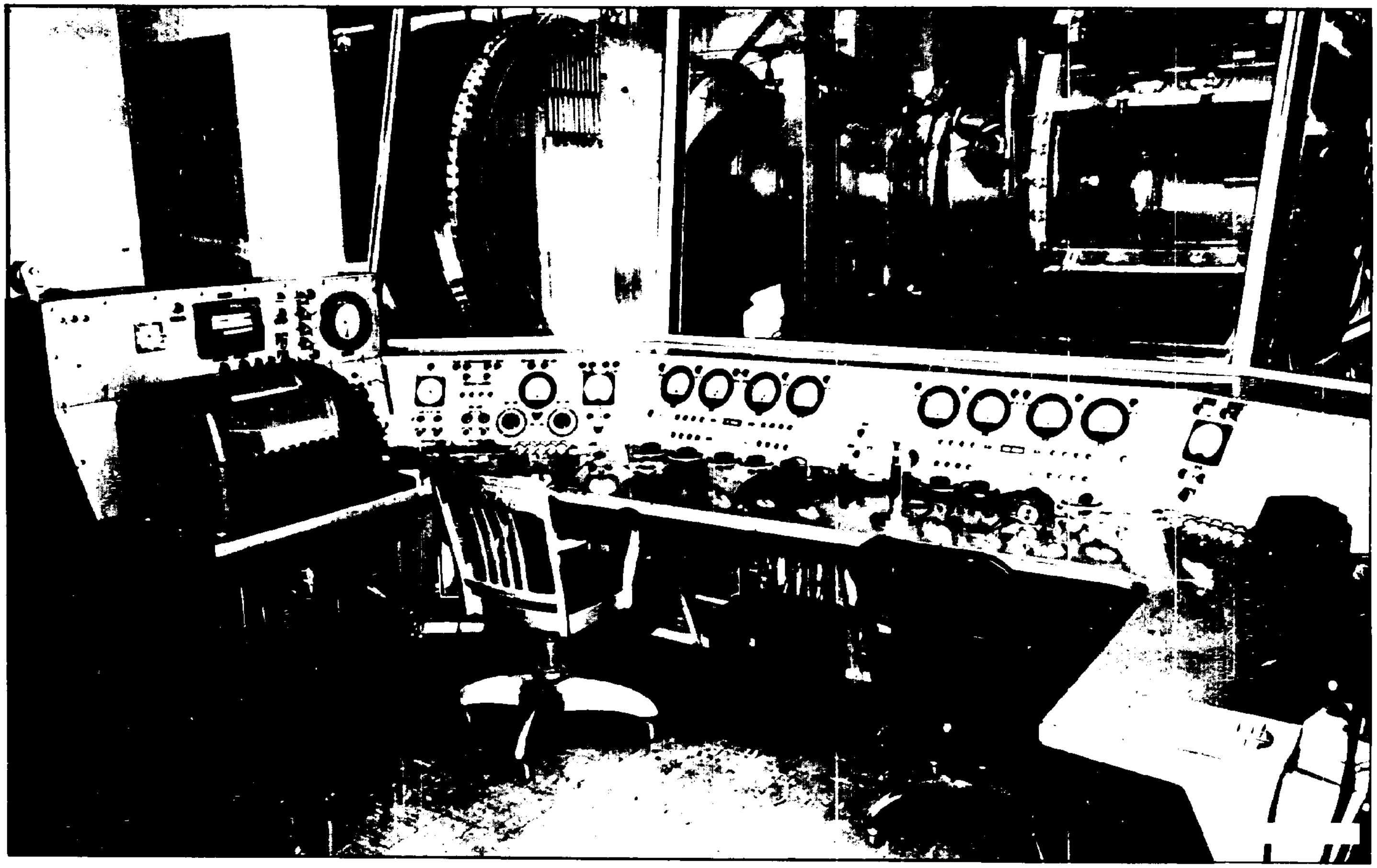


Figure 16 - 36-Inch Water Tunnel Operating Console

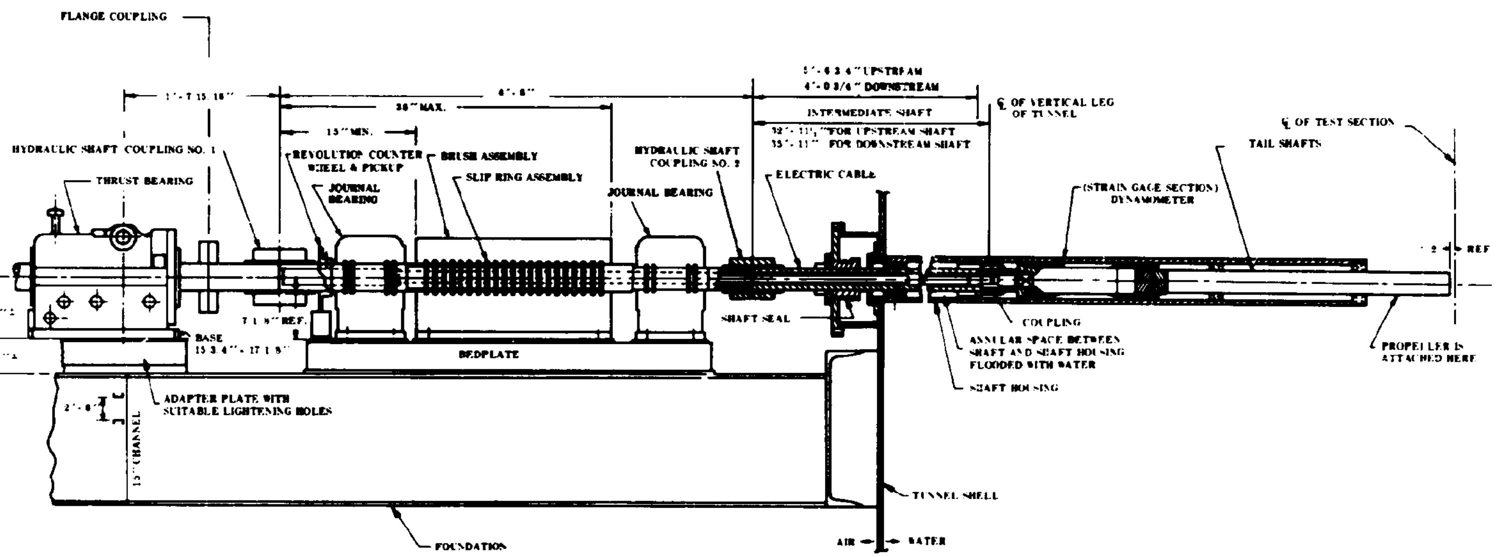


Figure 17 - 36-Inch Water Tunnel Dynamometer Shafting Arrangement

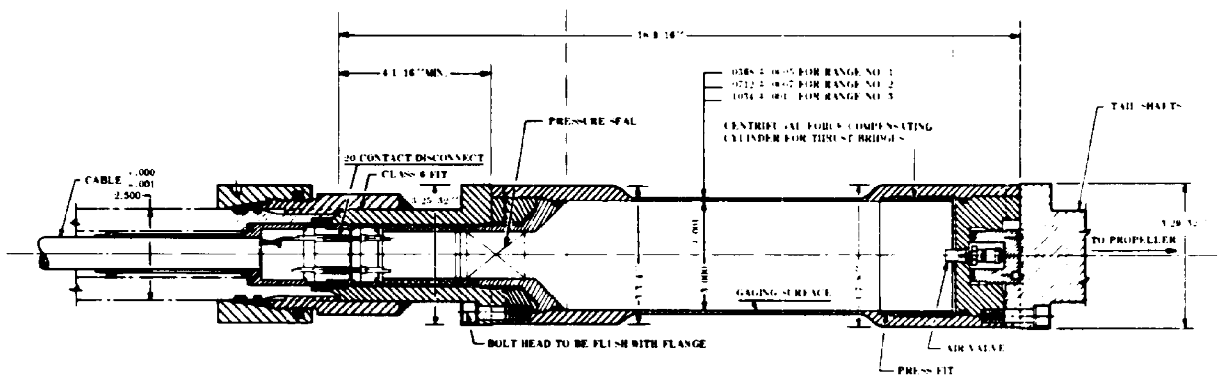
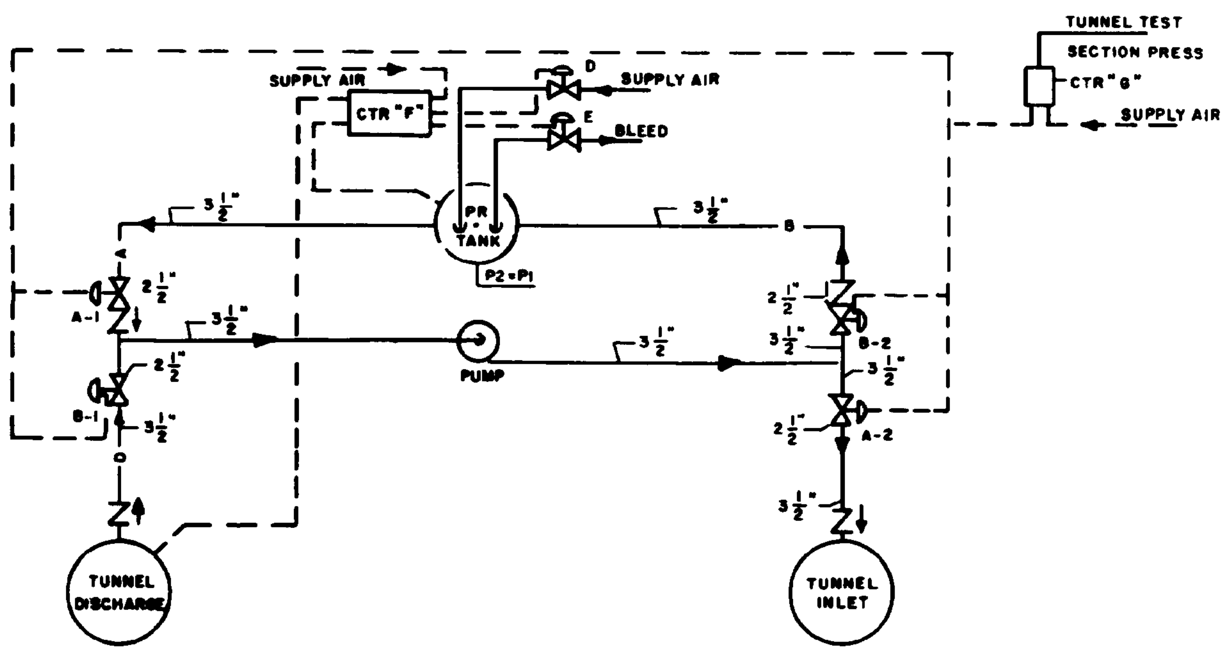


Figure 18 - 36-Inch Water Tunnel Dynamometer Assembly



TUNNEL PRESSURE RANGE AT ℄ OF CONTRACTION SECTION—MINIMUM 2 PSIA. MAXIMUM 60 PSIA WHEN TEST SECTION PRESSURE CORRESPONDS TO CONTROLLER "G" SETTING THE FLOW RATE THROUGH EACH OF MODULATING VALVES A1, A2, B1 AND B2 IS 100 GPM. EACH VALVE IS IN THE HALF-OPEN POSITION AND THE PRESSURE DROP THROUGH EACH VALVE IS 1.8 PSI SETTING CONTROLLER "G" FOR A LOWER TEST SECTION PRESSURE ACTS TO INCREASE THE RATE OF FLOW THROUGH VALVES B1 AND B2 AND DECREASE THE RATE OF FLOW THROUGH VALVES A1 AND A2. SETTING CONTROLLER "G" FOR HIGH TEST SECTION PRESSURE ACTS TO DECREASE THE FLOW RATE THROUGH VALVES B1 AND B2 AND INCREASE THE FLOW RATE THROUGH VALVES A1 AND A2. THE MAXIMUM RATE OF INCREASE OR DECREASE THROUGH EACH OPPOSITE ACTING VALVE SHALL NOT EXCEED 50 GPM AND THE MAXIMUM PRESSURE DROP THROUGH EACH VALVE AT 150 GPM FLOW RATE SHALL NOT EXCEED 4 PSI. CONTROLLER "F" ACTS TO MAINTAIN AIR PRESSURE ON PR TANK EQUAL TO TUNNEL DISCHARGE MANIFOLD PRESSURE BY MODULATING VALVES D.E ADMITTING OR BLEEDING AIR TO OR FROM PRESSURE TANK.

Figure 19 - 36-Inch Water Tunnel, Schematic Diagram of Pressure Regulating System

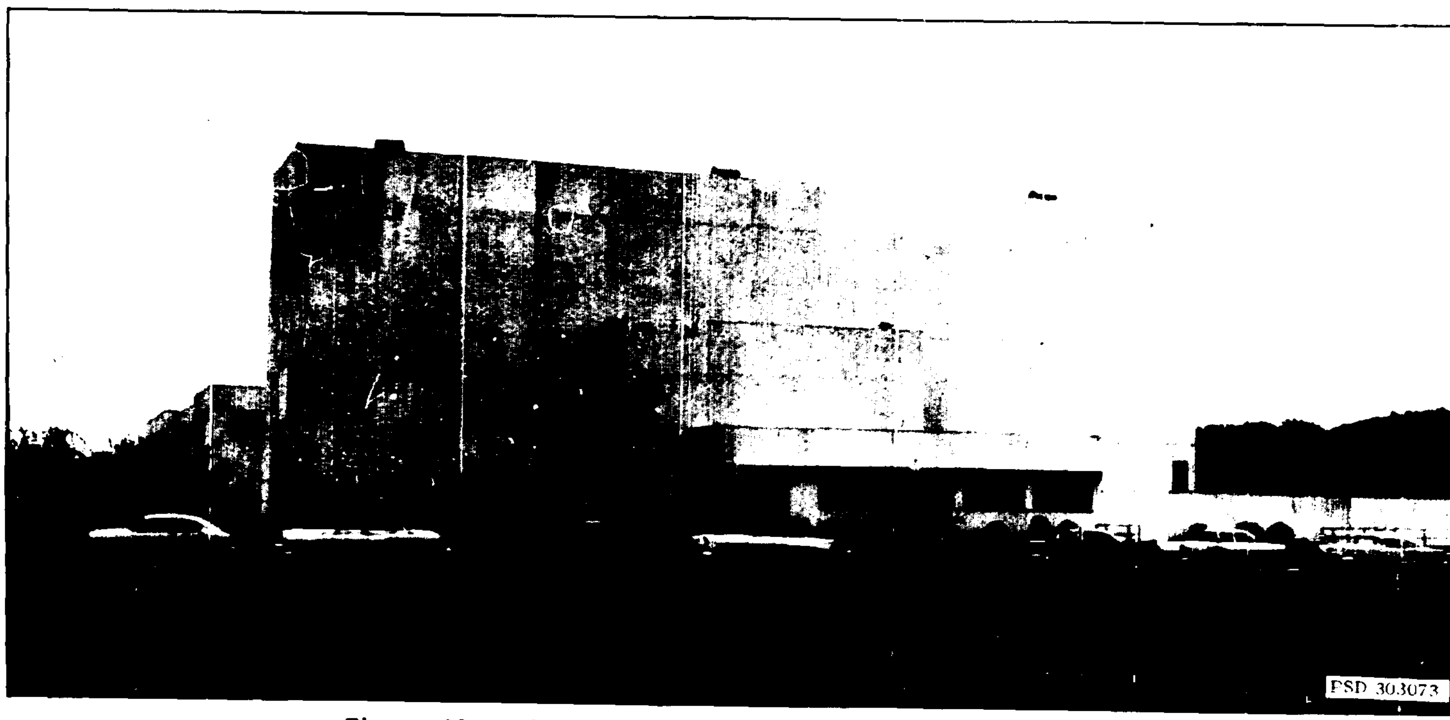


Figure 20 - 36-Inch Water Tunnel Building, Looking East

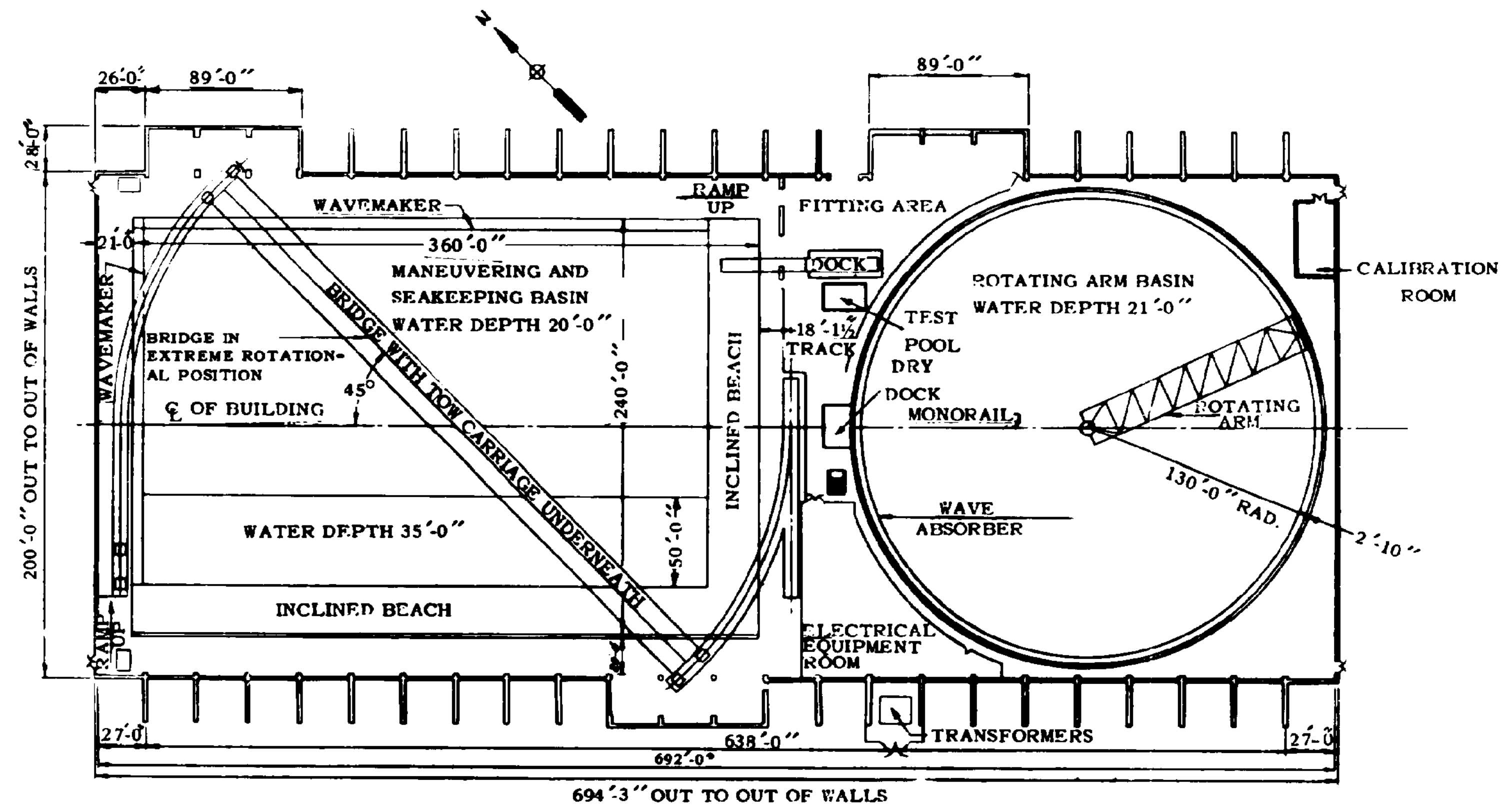


Figure 21 - Floor Plan of the Harold E. Saunders Maneuvering and Seakeeping Facilities

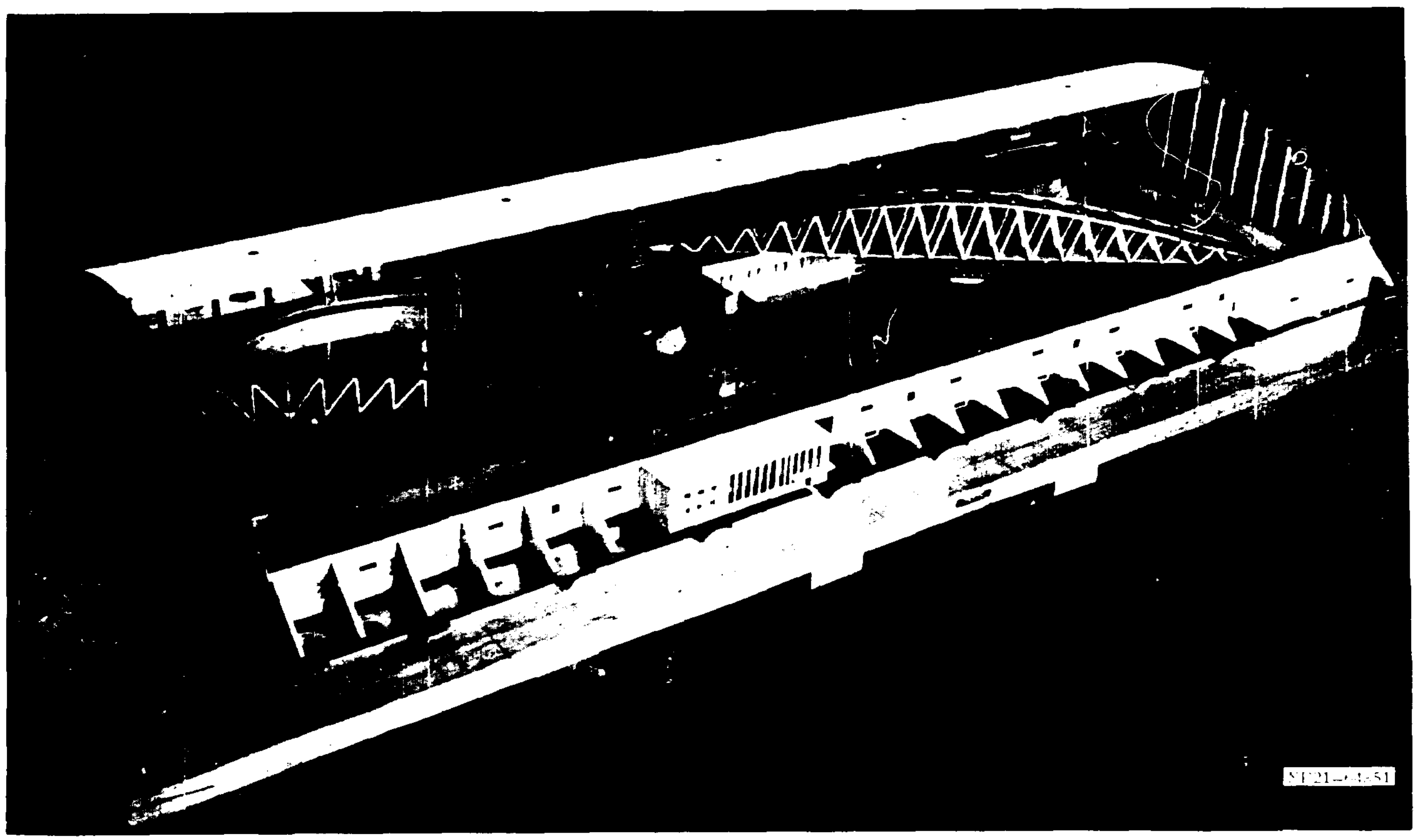


Figure 22 - Harold E. Saunders Maneuvering and Seakeeping Facilities, Model of 1/120-Scale Arrangement

Figure 23 - View of Rotating Arm Basin, Drydock, Center Island, and Towing Carriage

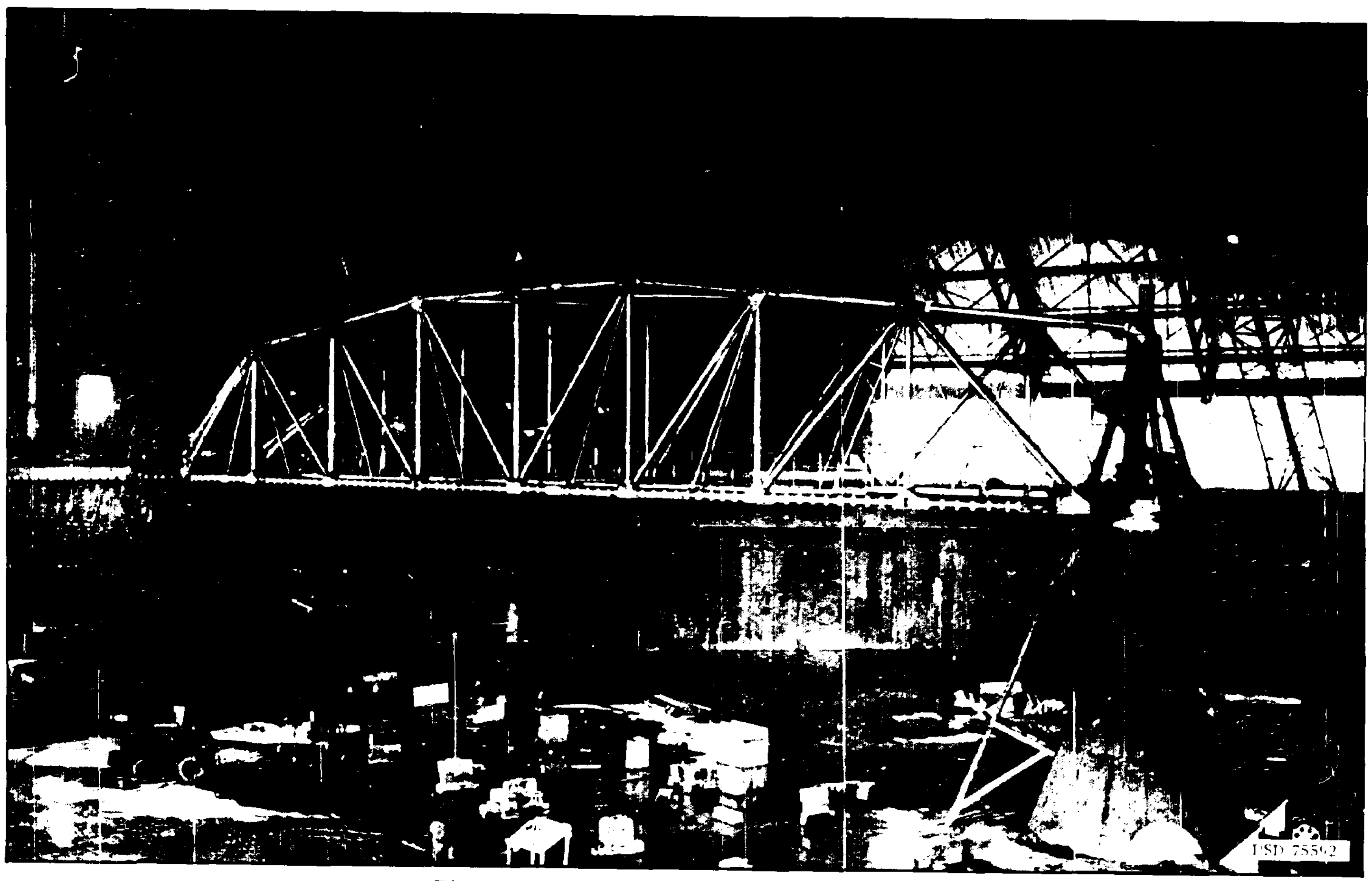


Figure 24 - Rotating Arm Being Erected

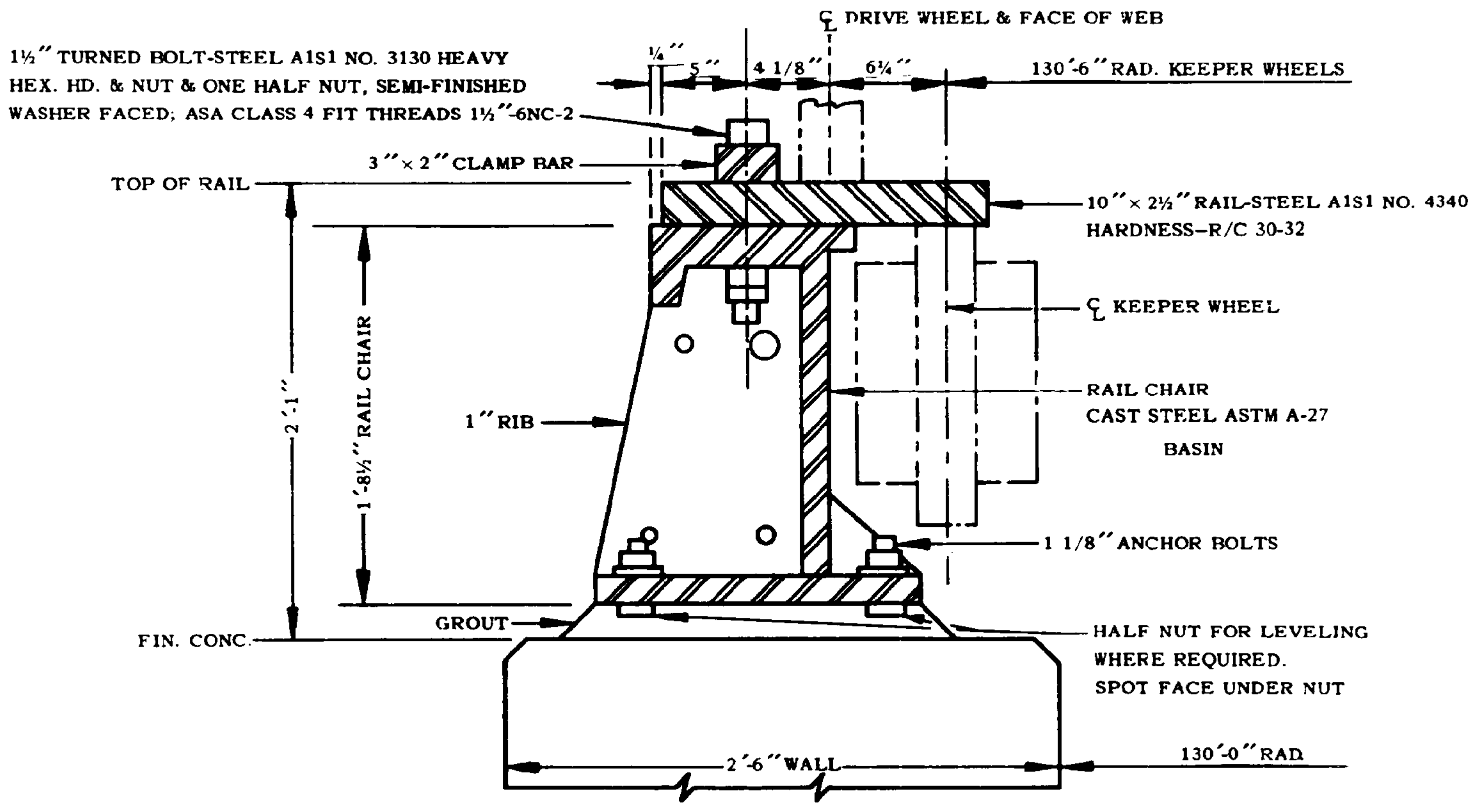


Figure 25 - Typical Section of Rotating Arm Peripheral Track

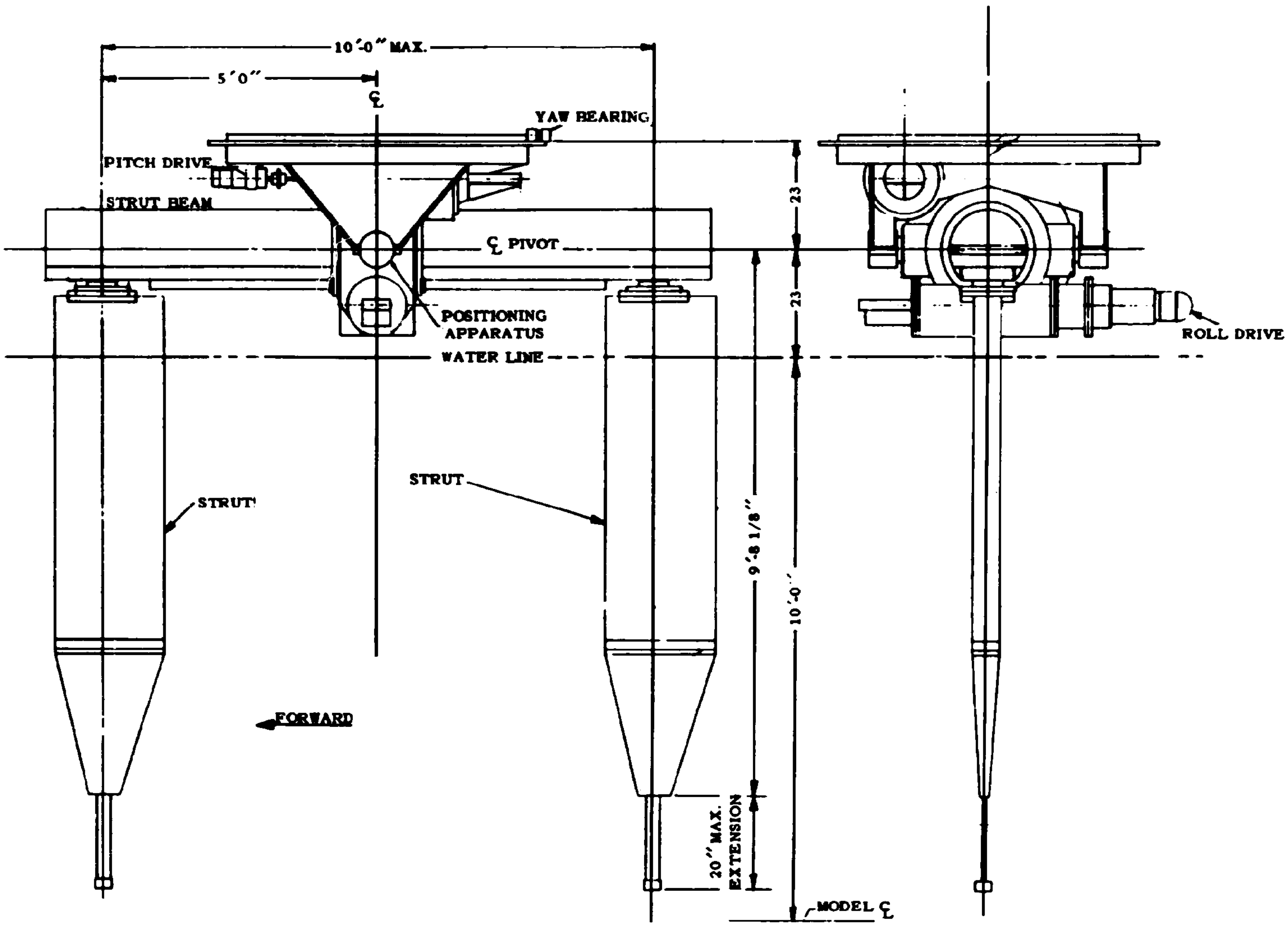


Figure 26 - Rotating Arm Submarine Towing Struts and Model Positioning Apparatus

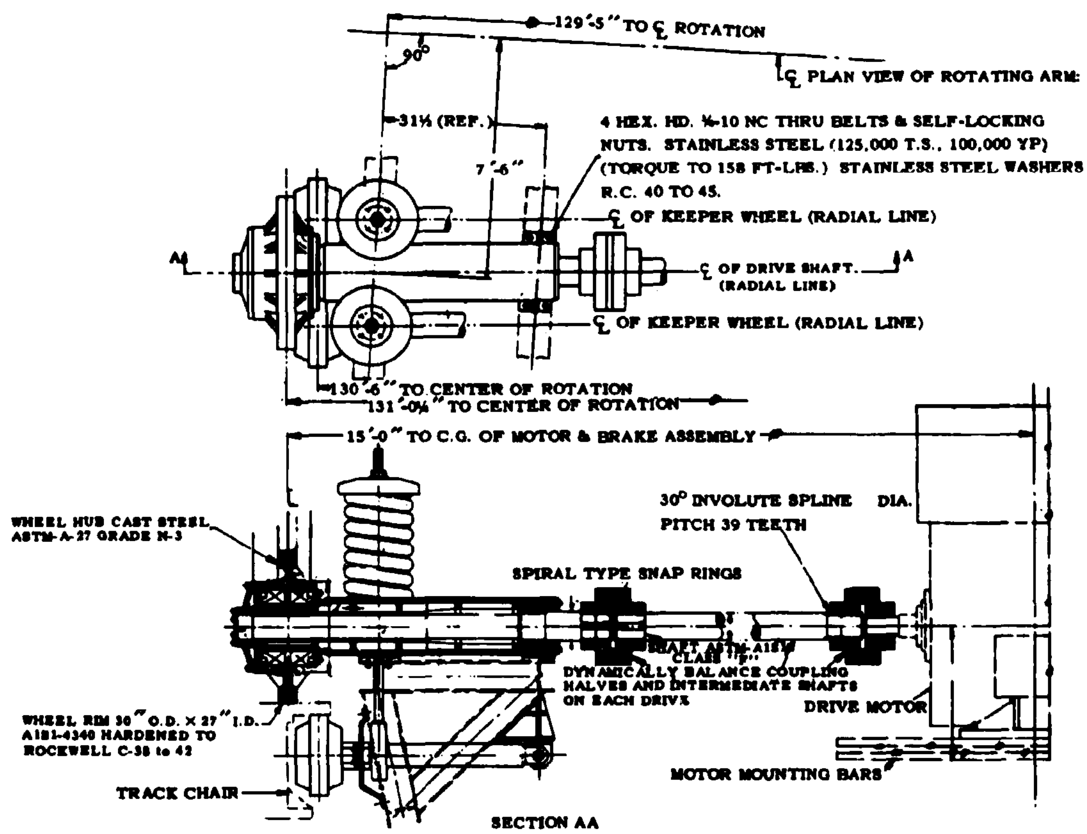


Figure 27 - Rotating Arm Drive Assembly

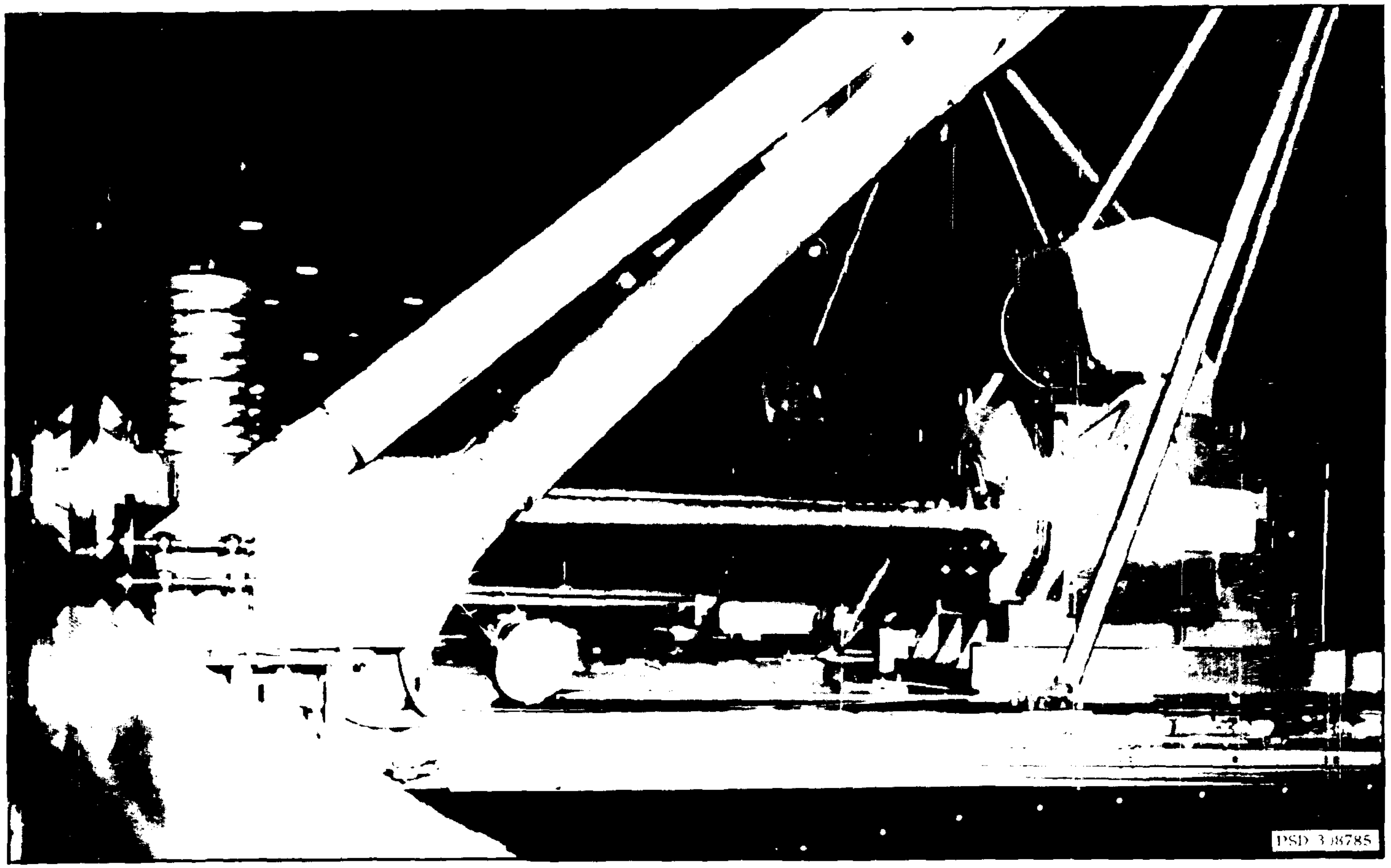


Figure 28 - View of Installed Rotating Arm Drive Assembly

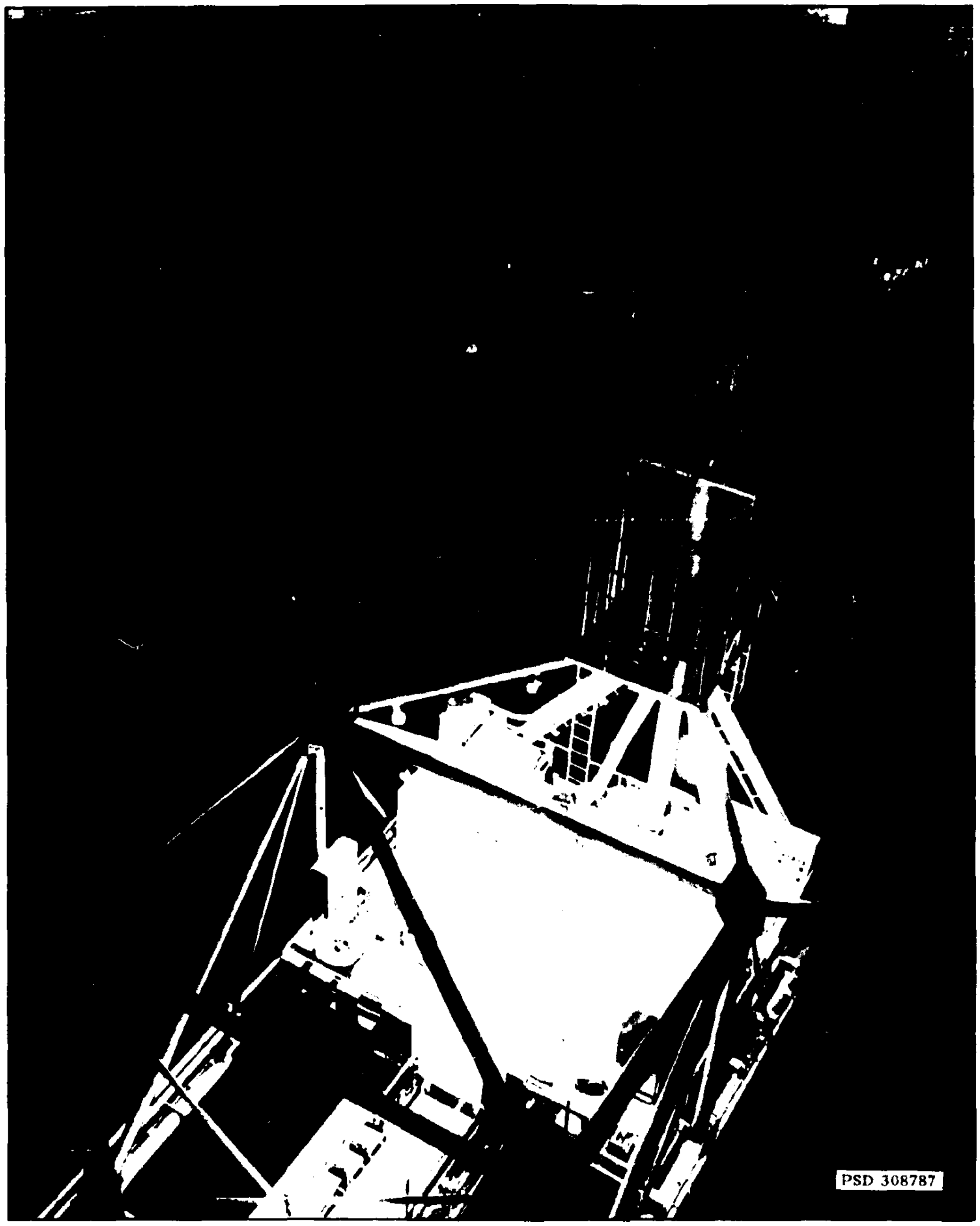


Figure 29 - Rotating Arm Slip Ring Structure

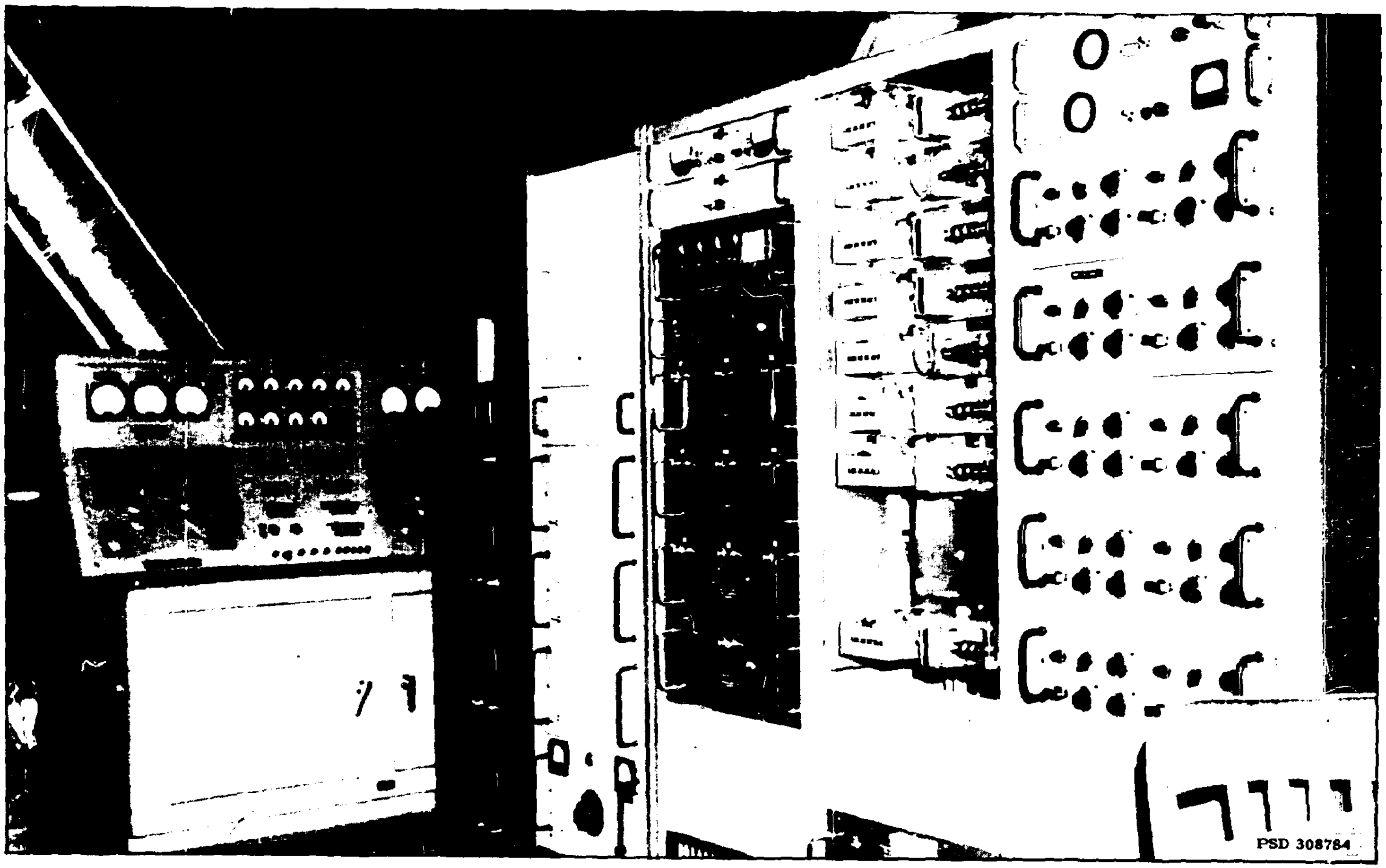


Figure 30 - Rotating Arm Indicating and Recording Instrumentation

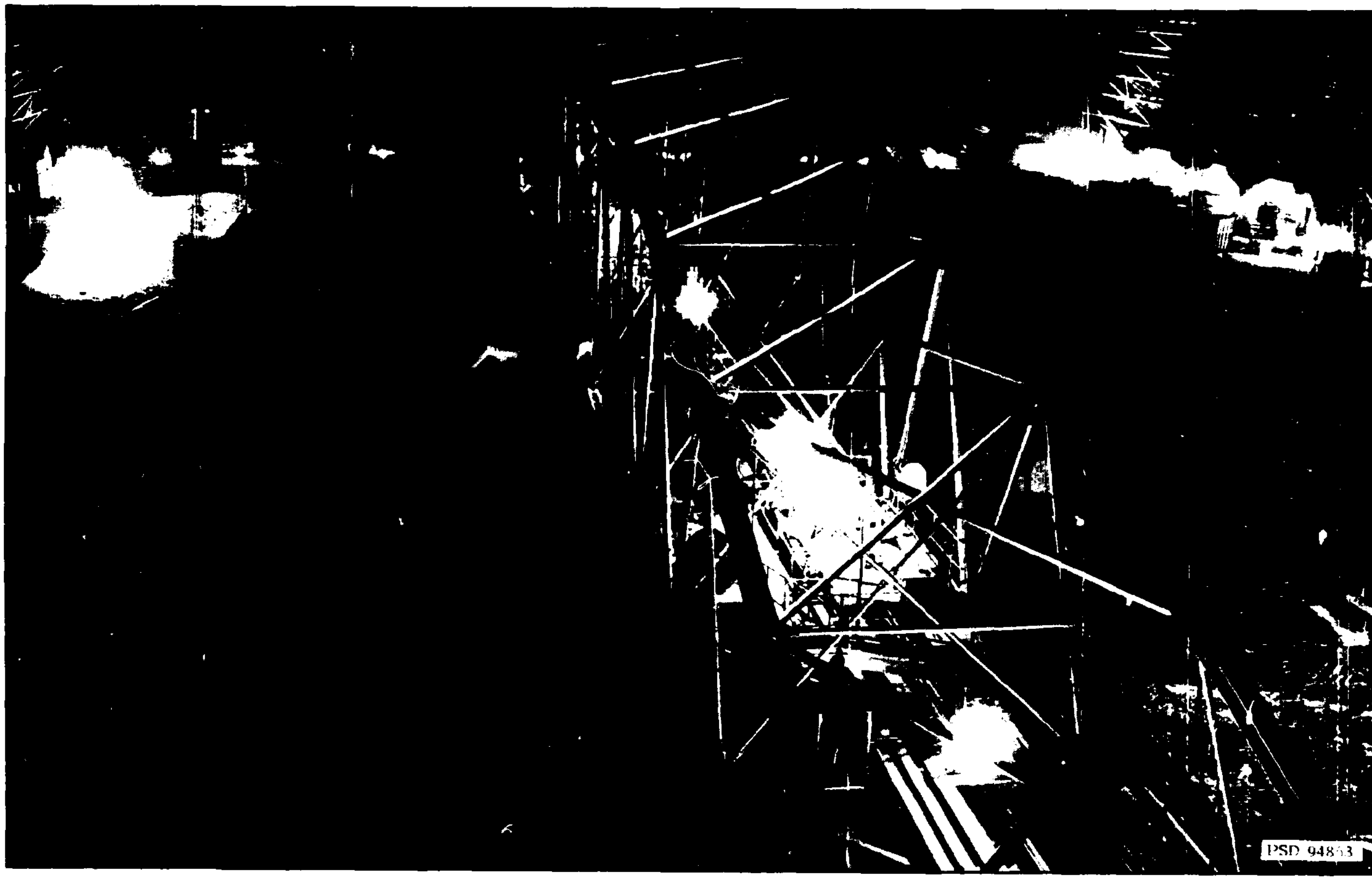


Figure 31 - View of Maneuvering and Seakeeping Basin during Construction

Figure 32 - Maneuvering and Seakeeping Basin, West Bank Wavemaker Domes

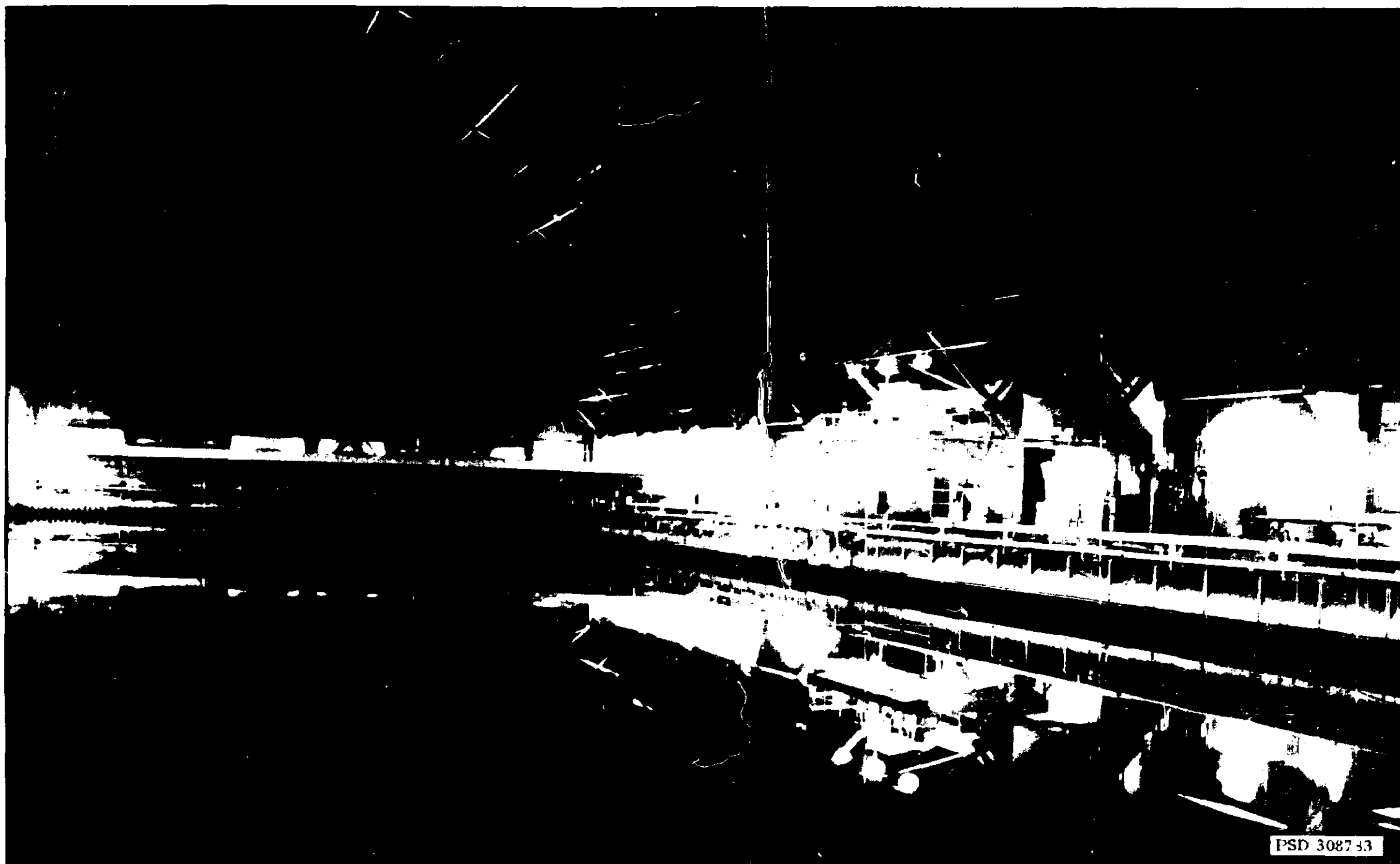


Figure 33 - Maneuvering and Seakeeping Basin, North and West Banks Wavemaker Domes

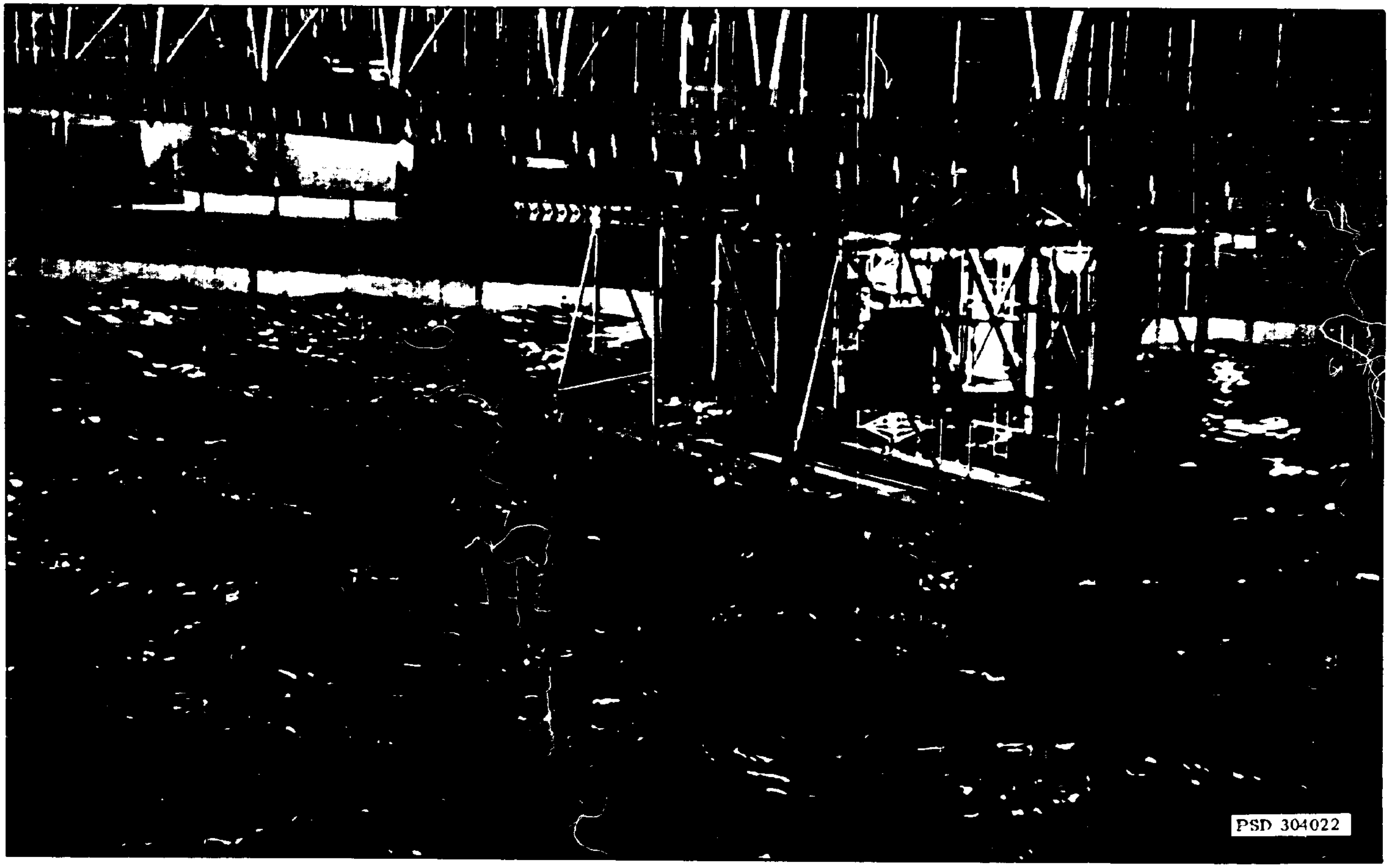


Figure 34 - Maneuvering and Seakeeping Basin Towing Carriage

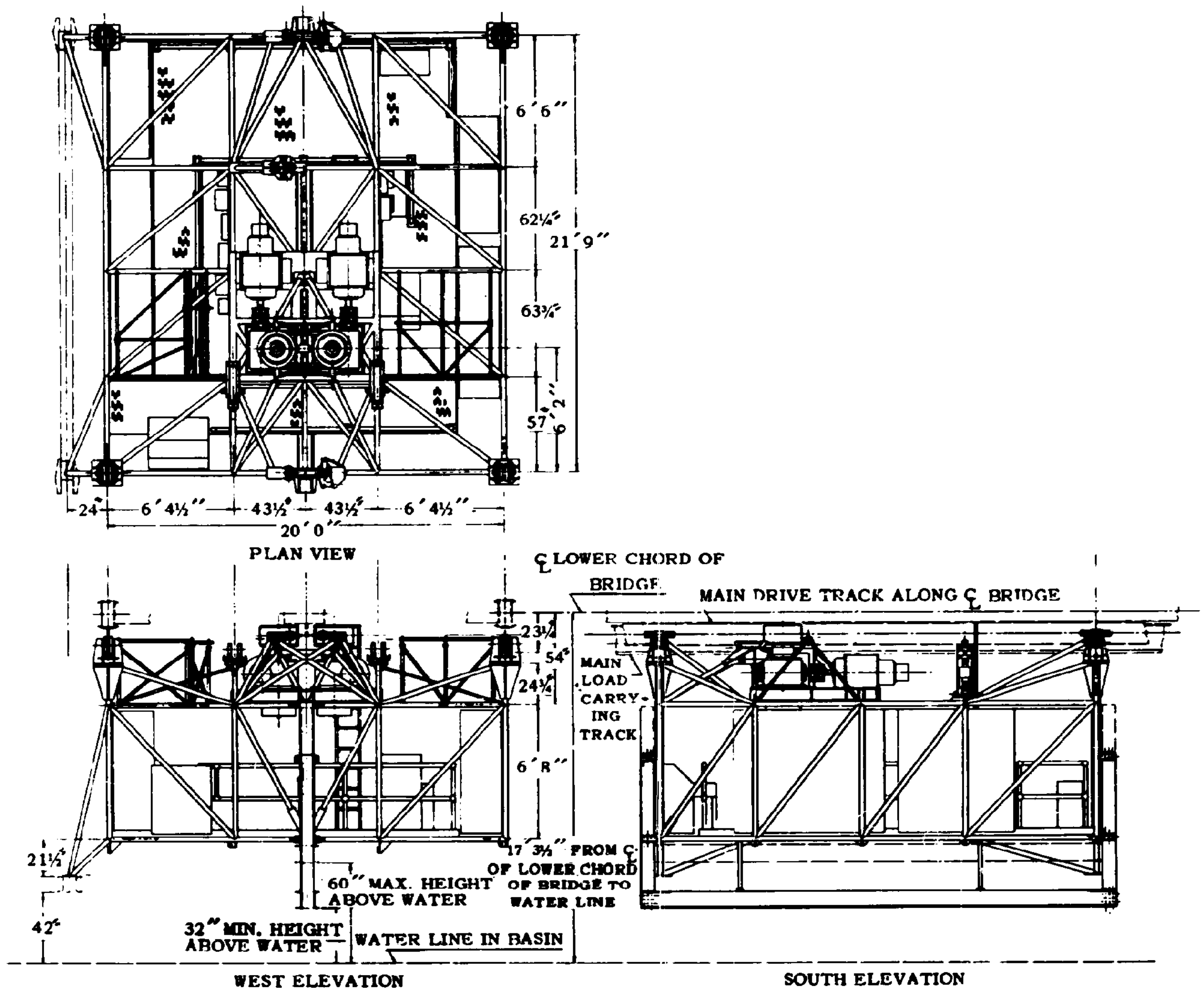


Figure 35 - Maneuvering and Seakeeping Basin Towing Carriage Assembly

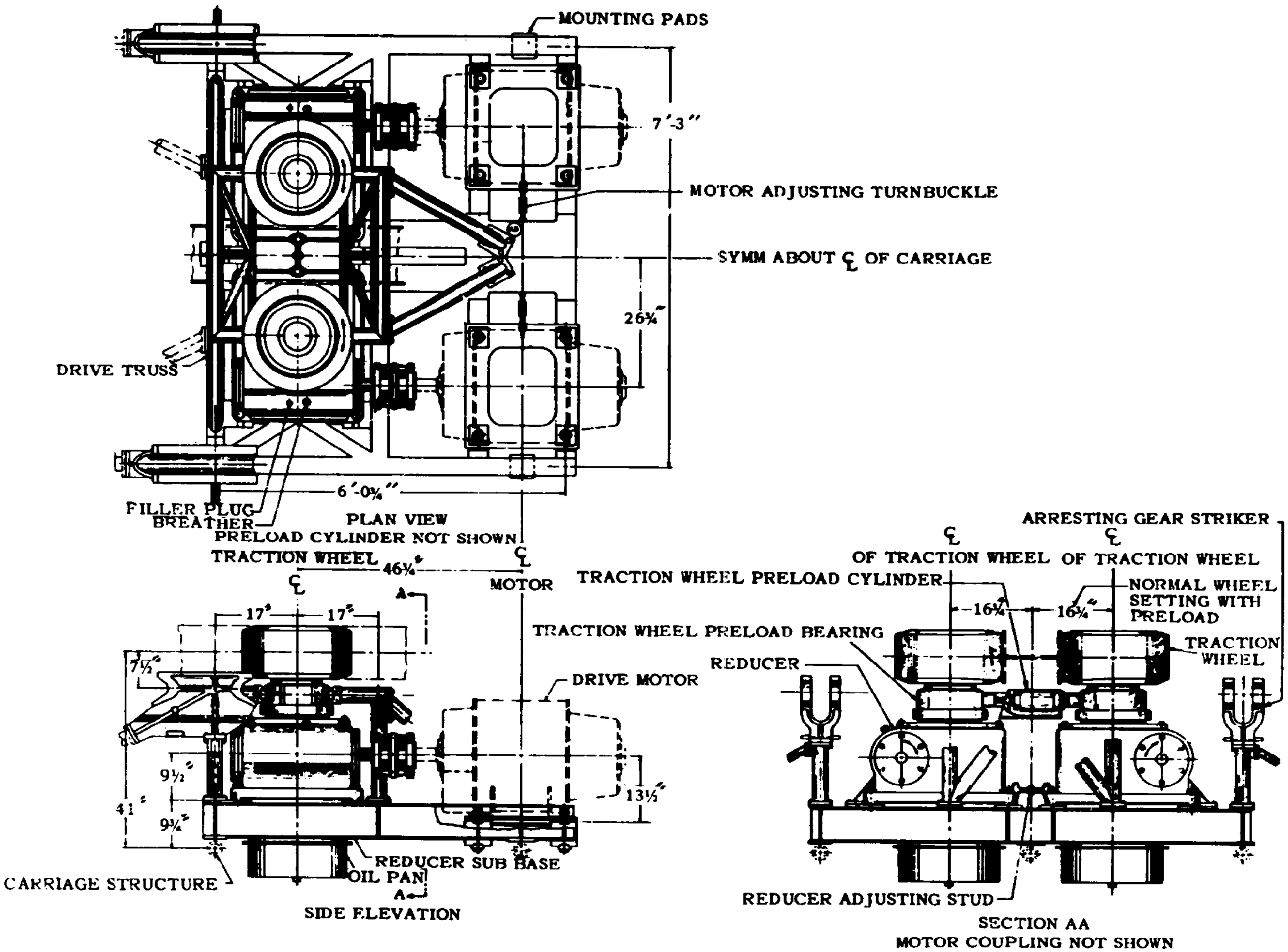


Figure 36 - Maneuvering Bridge Towing Carriage Drive Assembly

Figure 37 - Maneuvering and Seakeeping Basin Wavemakers in the Blower Equipment Room

Figure 38 - Maneuvering and Seakeeping Basin Hydraulic Linear Actuator Used in Electro-Hydraulic Wavemaker Control System

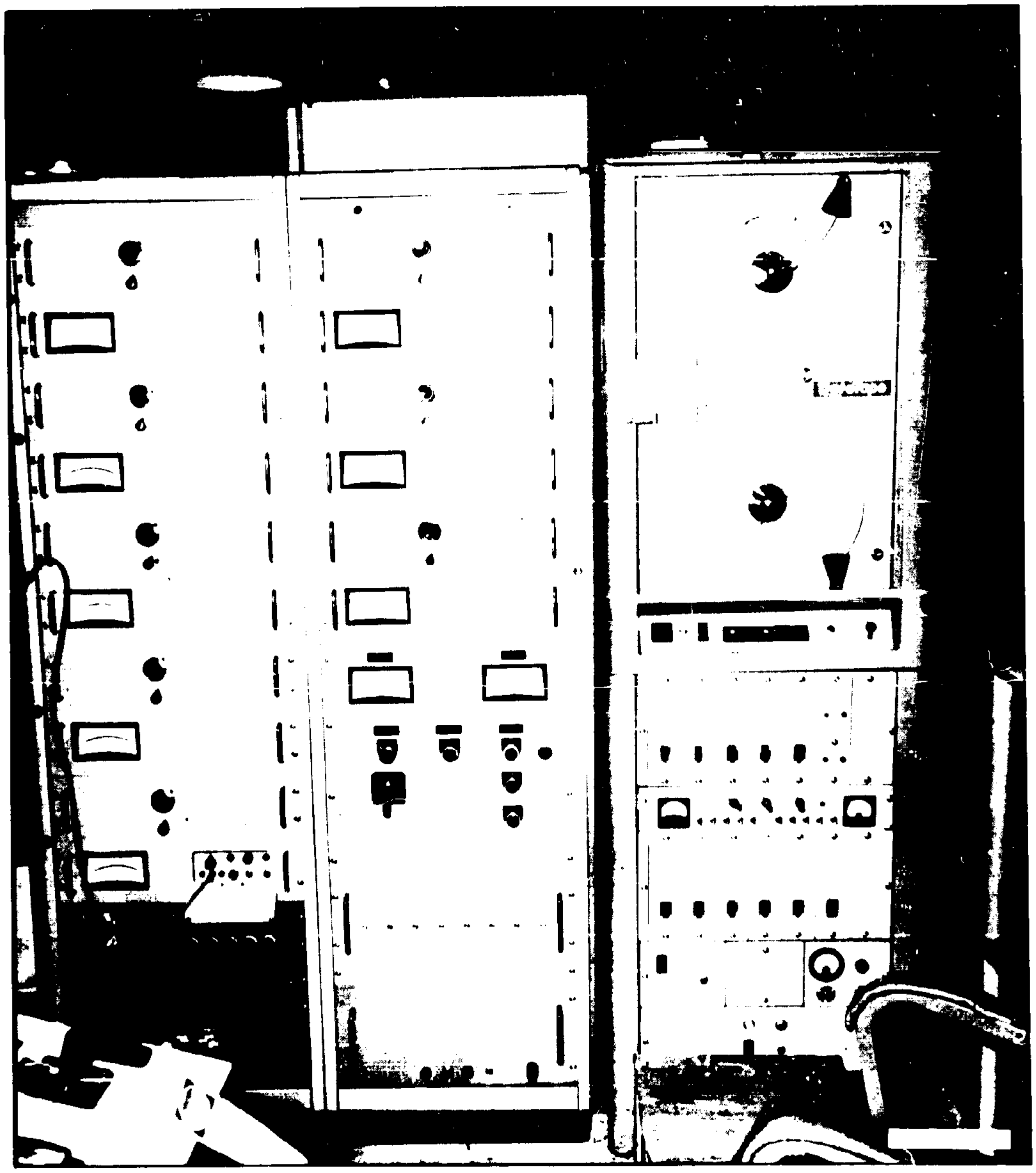


Figure 39 - Maneuvering and Seakeeping Basin Electro-Hydraulic Wavemaker Control Instrumentation

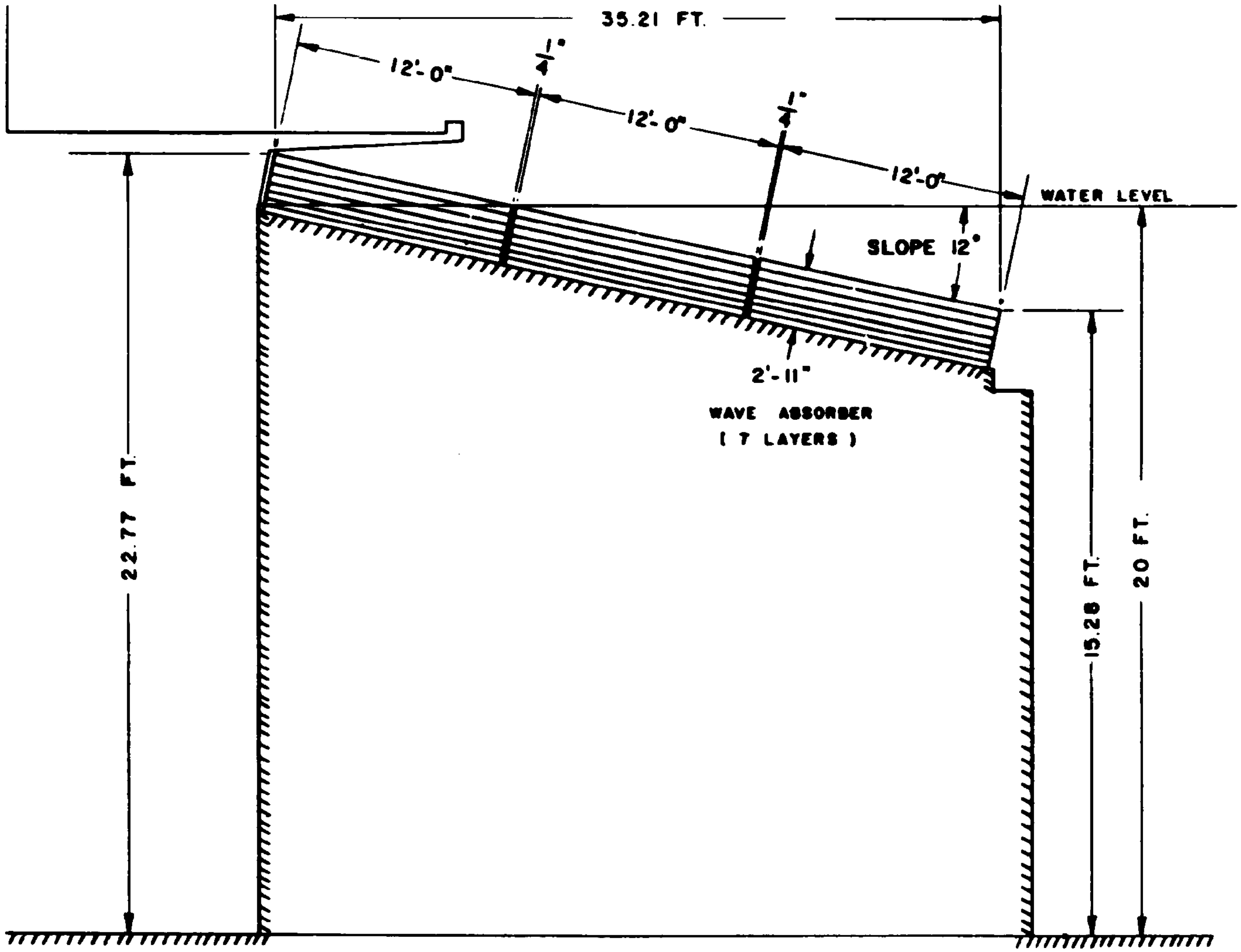


Figure 40 - Maneuvering and Seakeeping Basin Wave Absorber

Figure 41 - Harold E. Saunders Maneuvering and Seakeeping Facilities Building, Looking South

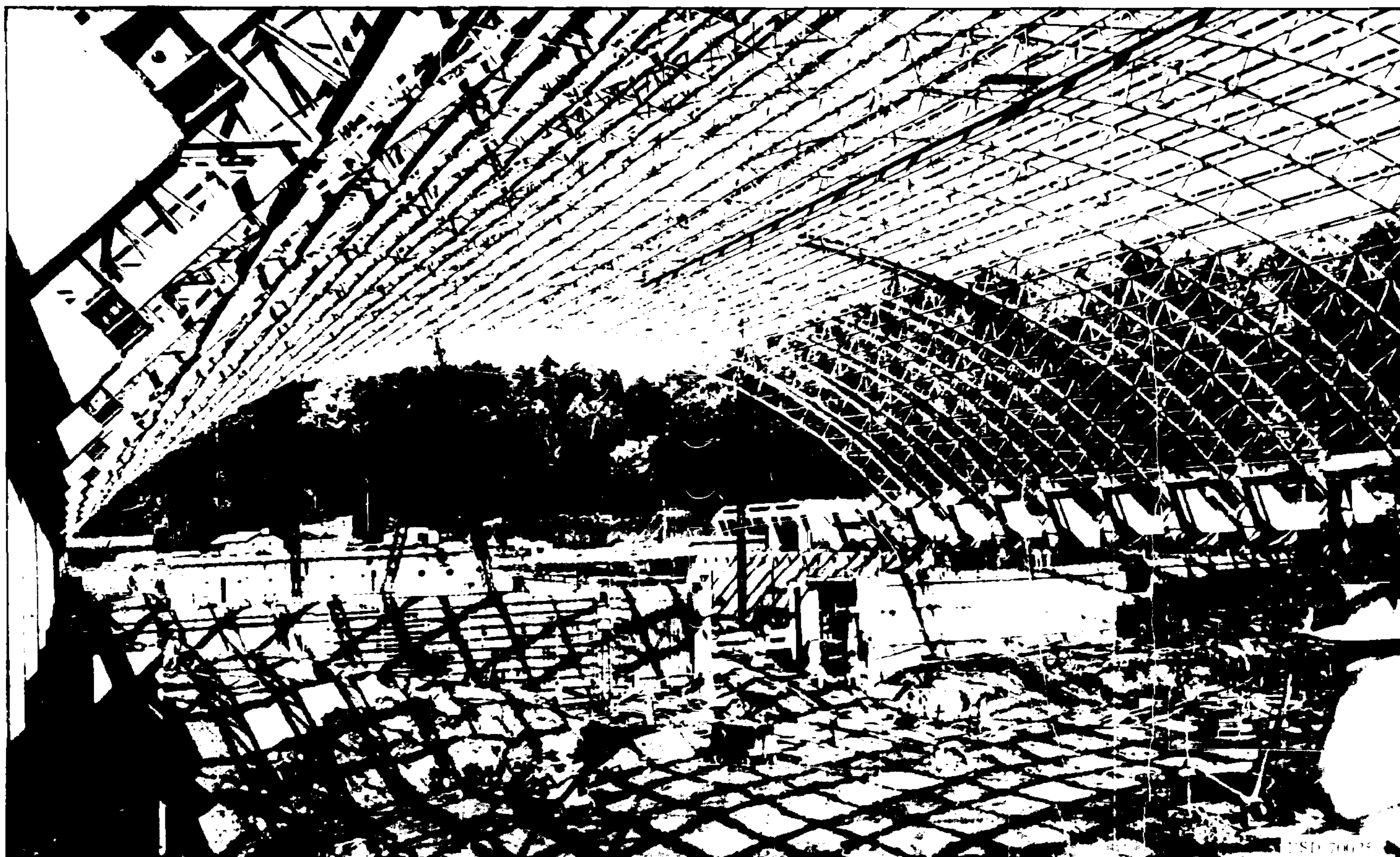


Figure 42 - Harold E. Saunders Maneuvering and Seakeeping Facilities, Roof Framing under Construction

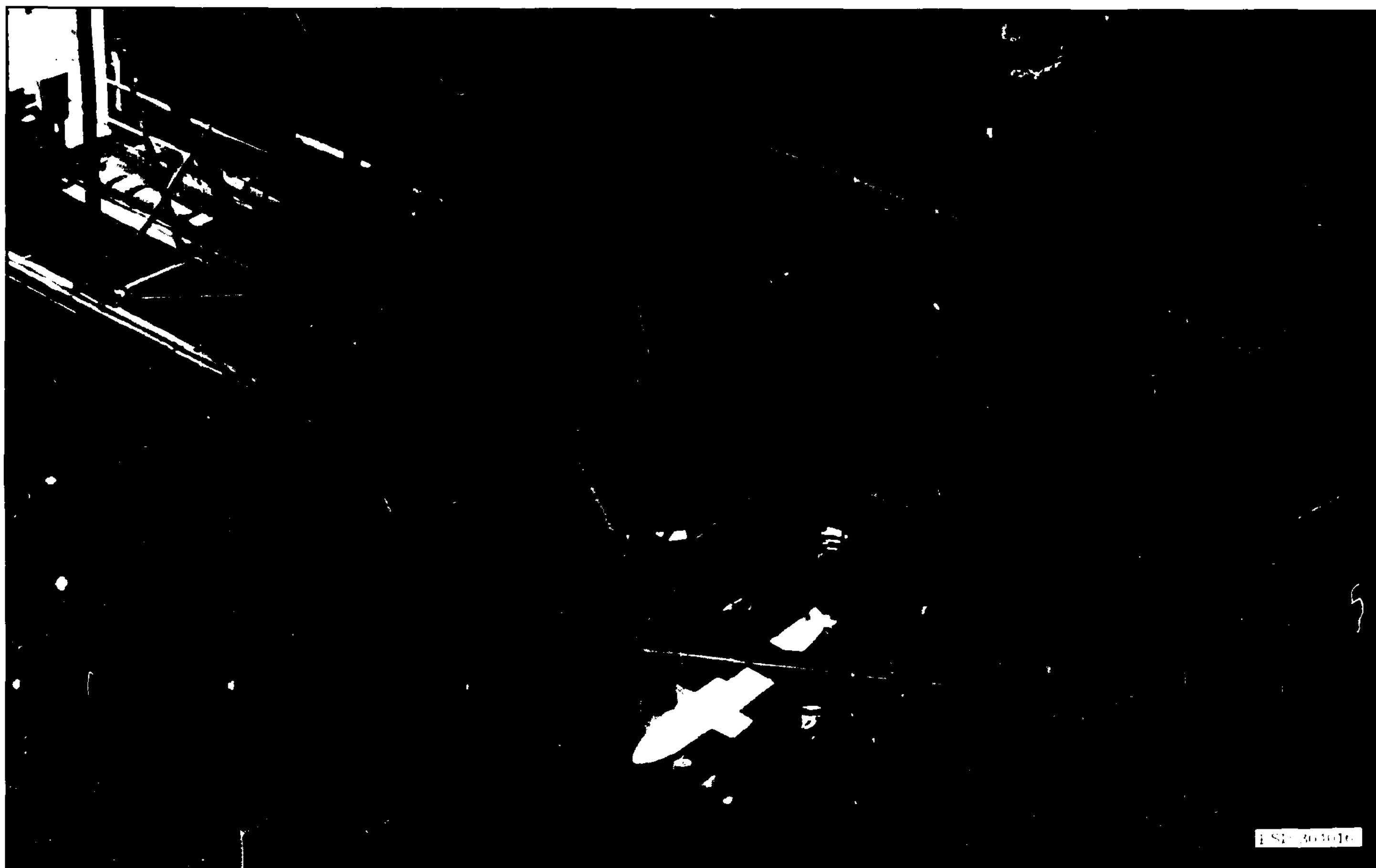


Figure 43 - Submarine Model Being Tested in Rotating Arm Basin

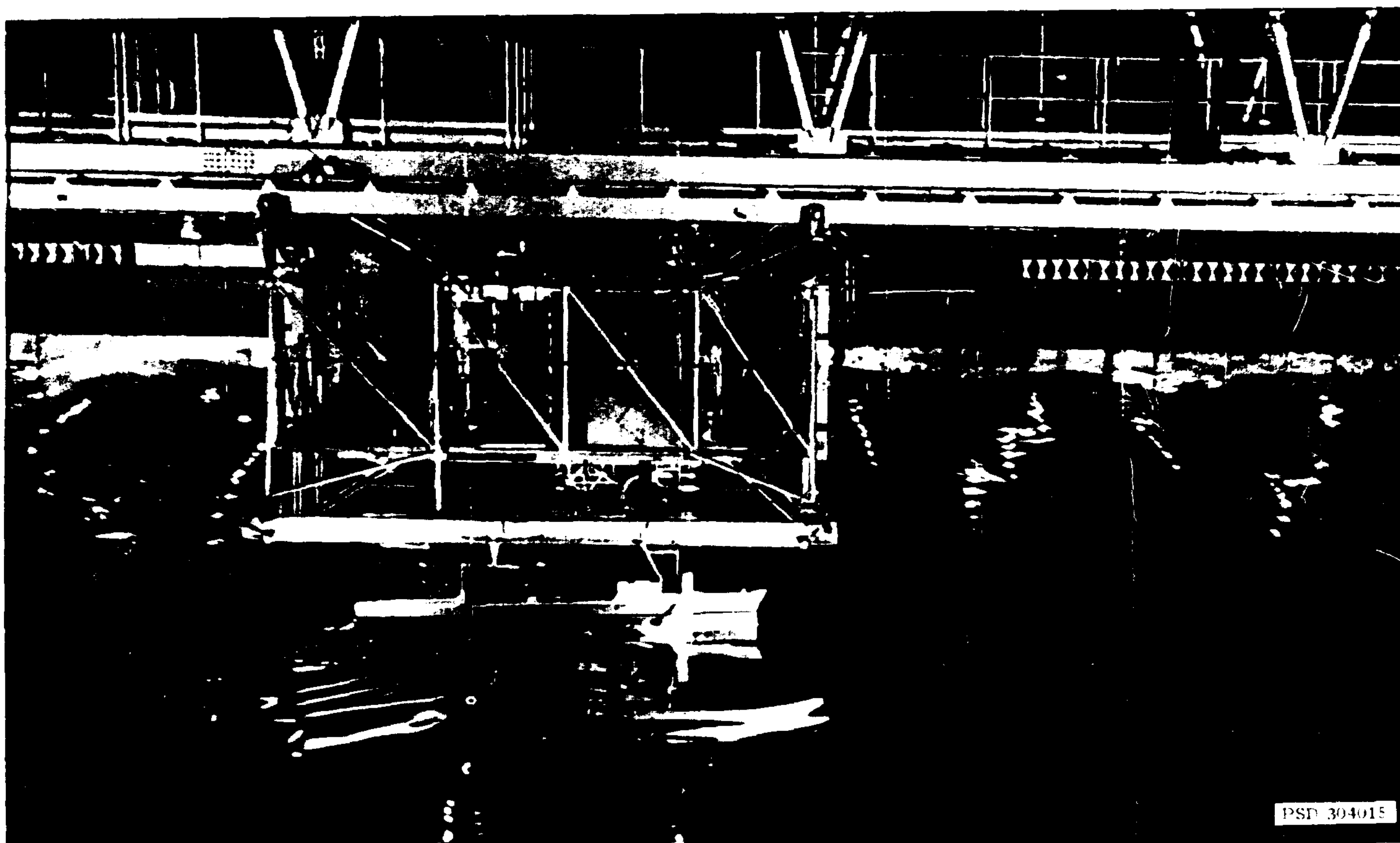


Figure 44 - Surface Ship Model Test in Waves in the Maneuvering and Seakeeping Basin

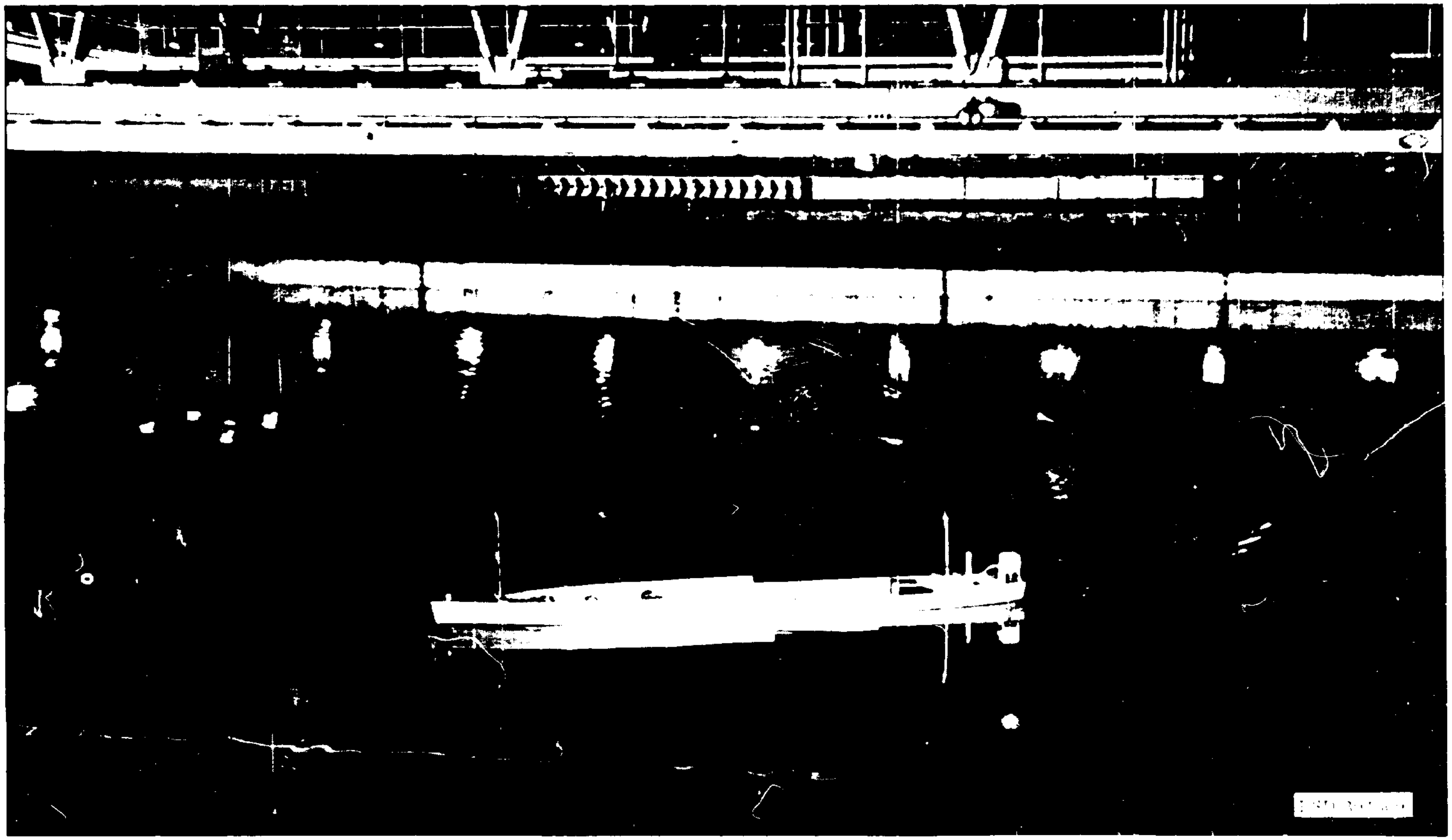


Figure 45 - Radio-Controlled Surface Ship Model Test in the Maneuvering and Seakeeping Basin

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David Taylor Model Basin. Report 1690.
TWO NEW HYDROMECHANIC RESEARCH FACILITIES AT THE DAVID TAYLOR MODEL BASIN, by W. F. Brownell. Paper presented at the Society of Naval Architects and Marine Engineers, Chesapeake Section Meeting, David Taylor Model Basin. Dec 1962. v, 73 pp., illus., plates, diagrs., refs. UNCLASSIFIED

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